Asymmetry in growth of the broiler chicken: histochemical and anatomical studies on the musculo-skeletal system

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ASYMMETRY IN GROWTH OF THE BROILER CHICKEN: HISTOCHEMICAL AND ANATOMICAL STUDIES ON THE MUSCULO–SKELETAL SYSTEM

by

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DEDICATION

To the soul of my beloved mother

To my dearest father, brothers and sisters

To my admired wife and son with love

ABSTRACT

The aim of this work was to study the apparent asymmetry in the breast muscles in some individual broiler chickens strain "Cobb 500", with a view to revealing the cause(s) of this asymmetrical growth. Birds showing apparent asymmetry in the breast were selected to study their breast muscles anatomically and histochemically in comparison with unselected birds as controls. The skeleton was studied in these birds too.

Selected chickens had heavier body and muscle weight, and higher growth rate than the controls. However, no significant differences were obtained between the two sides of the pectoralis or supracoracoideus muscles in either group of chickens, although the degree of asymmetry of the pectoralis muscle in selected chickens was higher than in the controls. The distribution of pectoralis muscle weight (degree of asymmetry) was normally distributed in both groups of chickens.

The histochemical study on the pectoralis muscle revealed that there were significant differences in fibre number and diameter between the anterior (region A) and mid part (region B) of the pectoralis muscle in both groups of chickens, in that there were more FG fibres in region B, whereas region A has more FOG and SO fibre number. The diameter of fibre type in region A was significantly larger than in region B.

Differences in fibre diameters were obtained between the right and left side of the pectoralis muscle. FG and SO fibres in the left anterior side of pectoralis muscle were growing significantly faster than in the right side in selected chickens, and control (against body weight or muscle weight). However, no significant differences were obtained for fibre numbers per square millimeter either between the two sides in control or in selected chickens.

Many measurements on the skeleton were taken to study the shape of the sternum and the rib-cage in both groups of chickens. The essential differences were the depth of the keel, shape of the rib-cage, and the shape of the ribs. In selected chickens, depth of the keel at the right side was significantly deeper than the left, consequently the width and height of the keel in the left side were significantly

greater than in the right side. As a result, the breast angle at the right side was significantly larger than the left one.

Statistical analysis revealed significant differences in the shape of the ribs between the two sides. Ribs at the left side had significantly greater: arc and chord length, enclosed area and height; than the right side. In addition the orientation dorsal angle of the left ribs was significantly greater than the right.

As a result, selected birds had faster bone growth, shorter, and less bone weight than the controls, in addition to the deformities in the shape of the keel, rib-cage, and ribs.

From the results, it would appear that the asymmetry in the shape of the keel and rib-cage could be the consequence of the high growth rate in body weight and increased breast muscle weight, without increase of the growth of skeletal mass. Such disproportionate change in body parts could be the result of direct selection for increased amount of breast muscles. This problem could be reduced by restriction of early growth and include the concept of the skeletal growth in the selection-programme indices.

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DECLARATION

The results in this thesis are entirely from my own work and no part of this thesis has been submitted for any degree in this or any other university.

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Chapter I

GENERAL INTRODUCTION

1.1 The Importance of Poultry Meat Production

Poultry meat is produced commercially in many parts of the world from chicken, turkey, ducks, geese, pigeons and guinea fowl. Broiler (or fryer) chickens and turkeys provide most of the total world production of poultry meat.

Broiler chickens are usually processed between 6 and 8 weeks of age and can be of either sex. Being young, immature birds, their meat is characteristically tender and their skin is soft, smooth and pliable. Since poultry production has been improved by controlling the environment systems and development of the commercial breeds by breeders, poultry production has become possible on a year round basis and therefore, the marketing of fresh poultry meat has become available all the year. As a result, this increased total production of meat, along with the use of frozen storage has allowed marketing of freshly frozen poultry meat on a year round basis. The variety of poultry meat products in recent years, such as the whole, oven-ready carcass, raw and/or pre-cooked carcass parts, boneless roasts, ground poultry meat, sausage products and any lunch-meat product, including frankfurters has attempted to broaden the market and increase per capita consumption of poultry meat through the development of convenience items for the consumer.

Why have poultry meat products have been the most widely used in the human diet? To give a clear answer to this question, a comparison between different

Table 1.1 — Feed Conversion and Eviscerated Yield in Different Agricultural Animals

Animal	Feed Conversion Ratio Kg.feed/Kg.meat	Eviscerated Yield Percentage %
Sheep	7.0–8.0	55
Cattle	7.0–8.0	50–62
Swine	3.0–3.5	72
Turkeys	3.0–3.5	80–90
Chickens (broiler)	2	75

Source: Morenge and Avens (1985)

meat products is necessary.

The most interesting comparative values, in view of the producers of the meat are: the feed conversion ratio (FCR), eviscerated yield and meat yield, whereas the most interesting comparative values, in the consumer's view are the price of the meat and the quality.

Agricultural animals differ greatly in their efficiency in converting feed into meat. Thus the most efficient animal will be the most profitable, because it could give more meat from the same amount of feed during the growth of an animal to market (slaughter) weight. The feed conversion values for meat producing animals are in Table (1.1).

Table 1.2 — Edible Raw Meat Percent of Carcass and Live Weight for Different Agricultural Animals

Meat	Percent of carcass weight	Percent of live weight(slaughter wt.)
Lamb	64 %	35 %
Beef	62 %	38 %
Pork	67 %	48 %
Turkey	75 %	64 %
Broiler	68 %	51 %

Source: Morenge and Avens (1985)

Table (1.1) shows that poultry and swine have high FCR but the poultry have the highest eviscerated yield which is the weight of uncut carcass and edible organs (minus blood, feathers, hair, hide, head, feet and inedible viscera and organ) of live market weight just prior to slaughter.

In fact, the carcass weight does not give the precise weight of the meat, because it contains bone and a variable amount of fat, tendons and cartilage. The percentage of the raw meat of carcass weight and also the percentage of the meat of live weight in table (1.2) give a clear evidence that poultry has the highest percentage of meat either of a carcass or live weight. The reason poultry yields a much higher percentage of edible raw meat from either carcass or live weight is its relatively lighter weight bones.

Table 1.3 — Meat Costs Per Pound of Cooked Edible Portion

Meat (ready-to-cook)	Percent edible portion after cooking	Retail price per pound* $	Cost per pound of cooked edible portion ($)
Beef: chuck roast	39.2	1.85	4.72
round roast	56.0	2.95	5.27
Pork: rib loin chops	37.6	1.47	3.91
Turkey: whole carcass	58.7	0.79	1.35
Broiler: whole carcass	50.2	0.54	1.08

Source: Morenge and Avens (1985)

* The price in 1983, Denver, Colorado, USA.

Although, the percentage of raw meat of carcass weight gives some idea of the meat provided for the consumer, the quality of meat should be clarified more by knowing the edible portion after cooking (i.e. after losing the moisture as well as fat lost during cooking) and the retail price per pound. Thus, considering the cost per pound of the actually edible meat, chicken and turkey are by far the most economical retail meat buys (table 1.3).

Since meat is largely protein with a relatively small amount of fat and an insignificant source of dietary carbohydrate, it is reasonable to compare meats based on cost per pound of protein rather than the pound of cooked edible protein. Data in table (1.4) gives evidence that eggs and poultry meat are the least expensive source of high quality animal protein. For this reason, poultry meat and eggs will

Table 1.4 — Cost Per Pound of Protein in Various Meat (price in $)

Meat (ready-to-cook)	Percent protein in uncooked edible protein†	Retail price per pound‡ ($)	Cost per pound protein ($)
Bacon(sliced)	8.40	1.79	21.31
Lamb shops	13.0	4.39	33.77
T-bone steak	14.7	3.49	23.75
Beef rib steak	16.9	3.59	21.25
Frankfurters(hot dog)	12.50	1.57	12.56
Ham	15.90	2.19	13.57
Pork chops	17.10	1.39	8.13
Beef roast(chuck)	18.70	1.85	9.90
Hamburger(beef)	17.90	1.69	9.45
Eggs(chicken)	12.9	0.54	4.19
Ground turkey	32.4	1.19	**3.68**
Turkey(whole carcass)	21.4	0.79	**3.70**
Broiler(whole carcass)	18.6	0.54	**2.90**

†Source: Watt, B.K. and A.L. Merrill, (1963).

‡ the price in 1983, Denver, Colorado, USA.

be a major economical source of edible animal protein in most developing as well as developed countries in the world in future years.

1.2 The Nature of Poultry Meat Production and Breeding

The progress of poultry development has been relatively very fast. This has been possible because of the biological advantages of fowl over mammals;

1. Chickens reach sexual maturity at about 20–21 weeks of age.

2. Also, the female chicken (hen) can potentially produce one fertile egg per day with relatively few non-production days per year.

3. Embryonic development can commence outside of and unattached to the dam's body, allowing continuing ovulation during the incubation period.

The incubation period for the fertile chicken egg is only three weeks before hatching. Thus, many more offspring are possible than with mammals. These unique biological advantages have been exploited by the poultry breeders, as exemplified by the hen that can produce 150 progeny per year, about hundred times her body weight. The cow produces 0.7 progeny per year on average, and thus produces two-third of her total body weight. The sow produces an average of 12 progeny per year, which is only 8 times her body weight (Morenge and Avens, 1985 chapter 4 p.85).

In view of commercial activity, growing birds for meat production is strikingly different from any another animal production system in a number of ways. First, the unit of production tends to be very large indeed and a single broiler house might contain 20,000 birds in the one undivided area. Second, the broiler birds system of production has a control over the environment as another feature of its intensiveness. Birds subjected to environments which are strictly controlled with regard to the mean temperature profile over the entire life-span, the rate of ventilation and, hence, the gaseous surroundings.

In this sense an exploration of bird growth for meat production provides a much more limited view of biological possibilities than the case with ruminants for example, because research on meat strains of poultry has tended to follow commercial feeding practice as I mentioned above. Also the output from a poultry meat enterprise is largely valued by its ready-to-sell mass. Unlike other forms of meat, poultry are not subjected to any detailed assessment of carcass compassion or quality other than perhaps a crude and subjective assessment of grade, and therefore the bulk of growth data consists of measures of live weight supported perhaps by gross yield of the dressed, oven-ready carcass. The reviewer, therefore, searches in vain for detailed research into the mechanisms and interactions of fat and protein deposition in poultry. The pattern of poultry meat production has remained so stable that it is difficult to find recent studies which even show the time course of live weight gain because the majority of growth studies compare treatments in terms of gross performance at the conventional killing age (Wilson, 1980). As a result of its tendency to obey the conventions of current commercial practice, research in poultry meat production therefore provides a very limited understanding of the biology of the bird.

1.3 Poultry Development as an Industry

In span the 20 years, 1940–1960, the broiler chicken changed from a bird marketed at 12 weeks of age to one marketed at 10 weeks, weighting 1.7kg and converting at the rate of 2.63g of feed per 1g of gain (see table 1.5). This rapid improvement in production efficiency provided the consumer and producer with a great economic advantage over other food commodities. The poultry industry has experienced continued rapid development since 1960.

The modern commercial meat bird is the result of prolonged selection for growth rate and heavy body weight with the advantage of the relatively short generation interval (generation interval can be calculated as the average age of the parents at the birth of their selected offspring, Falconer, 1981) offered by poultry. The success of this selection is shown in table 1.5 where the data have been adopted from those of McCarthy, (1977).

Table 1.5 — Estimated Broiler Performance Over Various Years

Year	Age at Killing (Week)	Body Weight (Kg)	Food Conversion Ratio (FCR) g food/ g gain
1947	12	1.3	3.45
1961	10	1.7	2.63
1967	9	1.9	2.38
1970	8	2.2	2.00
1988†	7	2.4	1.996
1989‡	7	2.5	1.976

Source: McCarthy, 1977.

†Cobb Breeding Company Annual Report 1988.

‡Cobb Breeding Company Annual Report 1989.

Current broiler data show how dramatic improvements in food conversion ratio and growth rate have been achieved over the last 40 years. This progress has not been entirely of genetic origin, but much of the development of broiler performance has been the result of intensive selection. Certainly, selection experiments with poultry have demonstrated adverse correlated change in traits related to fertility and the structure of the carcass and other side effects in the skeleton formation. These adverse correlated changes will be discussed in the next section.

1.3.1 Trends in Recent Broiler Chicken Production and Problems

Indeed, the phenotypic consequences of increasing the rate of growth which have been achieved by intensive selection for heavy body weight under *ad libitum* feeding, led to many problems in poultry production.

In turkeys, selection for growth rate and breast meat development in male turkeys has required the parallel development of artificial insemination (A.I.) techniques to ensure continuing reproduction, because males are unable to mate witth female since they become so heavy in body weight.

As poultry breeders have selected birds for early maturity, high efficiency, high appetite and fast growth, there is an apparent negative genetic correlation with reproductive efficiency and carcass composition. For example, hatchability of broiler and turkey eggs is much lower than that of eggs from layer chickens (broilers 82%, turkeys, 80%; layers, 90%) (Bazer, *et al.,* 1980). More basic knowledge concerning reproduction and growth is needed to improve reproductive efficiency of broiler and turkey without reducing growth rate and feed efficiency. Also, the current problem with fatty carcasses in recent broiler chickens is a consequence of the selection for increased growth in broiler chickens (Ricard and Rouvier, 1967; Proudman, *et al.,* 1970; Wethli and Wessels, 1973; Griffith, *et al.,* 1978). This degree of fatness is surprising since these chickens are slaughtered at an earlier stage of maturity than those of ten to fifteen years ago. The general trend seems to be that fat deposition in male broiler chickens has increased from 72 to 136 g/kg between 1967 to 1984 as shown in table 1.6.

Table 1.6 — Fat as Proportion of the Carcass of Broiler Chickens For the Period 1967 to 1984

Sex	Age at Slaughter (Days)	Fat Content (g/kg carcass)	Reference	Date
Male	56	72	a	1967
Male	56	106	b	1977
Male	59	104	c	1979
Females	59	104	c	1979
Males	49	130	d	1980
Females	49	149	d	1980
Males	49	122–136	e	1984

Sources:

a: Osbaldistan (1967)

b: Griffith, Leeson and Summers (1977)

C: Becker, Spencer, Mirosh and Verstrate (1979)

d: Leeson and Summers (1980)

e: Pesti and Fletcher (1984a,b)

This increased fat is widely believed to be associated with selection for large body weight. Summers and Leason (1979) suggested that increased fat in the recent broiler strains is due to the selection for maximum growth rate and large appetite for food intake. Nir, *et al.,* (1974) confirmed the above suggestion by their work and reported that the major reason for the increased fat content in the recent broiler breeds is the increased food intake. So if the broiler chickens are too fat because of genetic reasons, then selection for a leaner bird should be possible ! but unfortunately, the correlation between food intake:weight gain ratio (FCR) and fat deposition is negative (Pym and Solvyns, 1979; LeClerq, *et al.*, 1980; Touchburn, *et al.*, 1981; Griffin and Whitehead, 1982; and Hood and Pym, 1982), although Proudman *et al.*, (1970) and Lin, *et al.*, (1980) reported that there is positive genetic and phenotypic correlation between growth rate and fat increments. But in contrast to these general findings Wethli and Wessele (1973) reported a tendency for chickens with improved food intake:weight gain ratio (FCR) and large body weight gain to have high fat content. Reports such as this, in addition to the above findings suggest that the interrelationship between food intake:weight gain ratio, body weight and fat deposition should be critically examined because the excessive fat deposition in broiler chickens is a major concern in the broiler industry, therefore the main factor in any breeding programme should be concerned with reducing fatness without adversely affecting growth rate although the fatness is highly heritable (LeClerq *et al.*, 1980; Becker, *et al.*, 1981; and Cahner and Nitsan, 1985). However the potential of breeding for leaner broiler chickens has been reported by LeClercq, *et al.*, (1980) and Whitehead, *et al.*, (1984), but these leaner breeds are not yet available commercially. The other problem in the current broiler chickens is the skeletal abnormalities which will be reviewed in the following section.

1.3.2 Skeletal Abnormalities in Broiler Chickens

Abnormalities of broiler chickens are becoming increasingly common and it is by no means unusual to encounter flock incidences of up to 4% (Wise, 1970a). Many workers consider that such skeletal problems are the inevitable consequence of breeding birds of great growth potential and of feeding them a ration of high caloric density in environments providing little need or opportunity for exercise (Wise, 1970b).

The problem of abnormalities of poultry skeleton may be due to the breeders of broiler chickens and turkeys who have for many years placed their primary selection emphasis on body weight at market age and subjective body conformation score for improving breast muscle width (Havenstein, *et al.*, 1988). A secondary emphasis has been placed on viability, feed efficiency and recently freedom from leg problems. The poultry breeder has assumed that selection for growth rate would automatically result in proportional increases in all body parts. In fact, that assumption was not quite correct because it appears that selection for body weight and breast conformation has resulted in greater increases in breast than in leg muscle and skeletal mass. Furthermore, such disproportionate change in body parts appears to have contributed to leg problems (Wise, 1970b; Ferguson *et al.*, 1974; Andrews *et al.*, 1975; Wise 1975; Hay and Simon 1978; Summers *et al.*, 1978; Havenstein *et al.*, 1988; Steven and Salmon 1988) and the rib cage and sternum deformation (Swatland, 1979a; Hogg, 1982 and Swatland 1984).

Havenstein, *et al.*, (1988) have listed the documented reports and studies of skeletal problems in meat-type poultry which is related to the genetic basis as following:

1. the heritability of leg problems in broilers are moderate to high (Serfontein and Payne, 1934; Leach and Nesheim, 1965, 1972; Riddell, 1976);
2. the level of leg problems differ substantially in different broiler and turkey strains (Hay and Simons, 1978; Veltmann and Jensen, 1981; Nestor *et al.*,

1985, 1987);

3. broilers respond to selection for a decreased incidence of leg abnormalities (Serfontein and Payne, 1934; Leach and Nesheim, 1965, 1972; Riddell, 1976);
4. the incidence of increased leg problems is the consequence of selection for increased body weight (Nestor, 1984); and
5. selection for increased shank width reduced the number of leg abnormalities and improved walking ability in turkeys (Nestor, *et al.,* 1985, 1987).

Thus, the main cause of the leg problem as it is hypothesized by Nestor, *et al.,* (1985) is that direct selection for increased amount of breast muscles as well as for greater total body weight had caused an increase in the total body weight and breast muscles faster than the muscles and bones of the legs, and that this disproportionate change had caused an inherent weakness in the bird, which results in leg problems. Swatland (1980) explained the cause of the genetic skeletal defects, which is related to the differences in the degree of maturity between body weight and the skeletal system. This explanation from Swatland (1980) supports the theory of the pioneer work of Sir John Hammond and his school at Cambridge, who pointed out that the growth of each component of the body tends to follow a temporal pattern similar to that of live weight changes, in proportion resulting from the fact that the components are not of the same size when differentiated in the embryo, have different asymptotic weights and have growth curves which are not necessarily in phase with one another. Hammond described it as 'early' or 'late' maturing relating to the sequence in which they reach their maximal absolute growth rate.

The relationship between mature body size and the potential for lean meat production has been observed in poultry. Thus, at equal body weights the skeletal system may be less mature in broilers, which have been selected on the basis of the meat yield, than in layers (Wise, 1970a). Therefore, broilers are afflicted by a number of genetic skeletal defects. Asymmetrical or abnormal development of the sternum may occur in birds at market weight and be a cause of downgrading, as has been reported by Swatland (1984).

1.4 Cobb Breeding Company

Cobb have been breeding poultry for some 70 years. Today their range of broiler breeding stock is recognized as one of the most versatile in the world.

Joint research in the United States and Europe places Cobb in a unique position among world breeding resources of the parent Upjohn company.

At Cobb Breeding Company (U.K.), there is a commercial broiler breed called **'Cobb 500'** that has been improved genetically to increase live body weight, feed consumption and feed conversion ratio. This breed of broiler chickens reaches 2.96 and 2.46 kg at 56 day of age for male and female respectively, but the breeders at Cobb have recently recognized a percentage of the birds they breed that display asymmetric growth of the breast and which consequently are not saleable. This problem will be investigated in both the breast muscles and the rib cage by using anatomical and histochemical methods.

1.5 Development of Project

The initial aim of this project was to investigate the cause(s) of the presumed asymmetrical growth in the breast muscles of some broiler chickens. These birds were identified manually by a skilled handler at Cobb Breeding Company and called selected chickens and compared to randomly chosen birds as a control.

Anatomical and histochemical methods were applied on the two groups as described in chapters III and IV respectively. However, preliminary results showed that the selected birds were not particularly asymmetrical in terms of pectoralis muscle weight and structure, so it was decided

(i) to investigate muscle structure in the most highly asymmetrical muscles obtainable, and

(ii) to improve the accuracy of selection using an ultrasonic technique.

The most asymmetrical muscles showed no consistent differences from the corresponding extreme of the control group (Chapter V); however as a consequence of the introduction of the ultrasonic technique (Chapter VI) it was found that many birds thought to exhibit asymmetry of the breast muscle in past showed asymmetry in the geometry of the thoracic skeleton (rib-cage and sternum).

Therefore, in the remaining available time, this skeletal asymmetry was qauntified in a further group of birds, selected by ultrasonic technique (Chapter VII).

CHAPTER II

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Chapter II

MATERIALS AND METHODS

2.1 Chickens

Commercial meat-broiler male chickens of the **COBB 500** were used throughout this study. Newly hatched birds were randomly chosen by Cobb Breeding Company from a large house and sent to the Animal House, Durham University, to be used as controls, whereas other birds at 20 days of age were identified manually by an expert handler at Cobb as showing asymmetrical growth in the pectoralis muscle. The results obtained with these two groups are described in chapters III and IV. In results of chapters V and VII, the selected birds were identified by an ultrasonic technique (see chapter VI), and compared with the control birds from chapter III.

Control chickens were received from Cobb at hatching date, i.e. one day old, whereas the selected chickens were received at 20 days of age, Both groups of chickens were reared in the Animal House until 150 days of age for anatomical and histochemical studies (see chapter III and IV). More selected chickens by ultrasonic technique were received from Cobb at age 50 days and reared until 100 days of age for more investigation in chapter V and VII.

2.2 Housing Conditions

Control and selected birds were housed in a pen with a solid floor with wood shavings. Heating was provided by hot air. During the starter period of the control birds (1-20 days) additional heat was provided by electric brooders, after the first week the temperature was gradually reduced until the end of the starter period of the control birds. The birds were then maintained at 20 $\pm$ 2^{o}C until the end of the experiment. Lighting was constant and ventilation was provided by electric extraction fans. Food was supplied by Cobb Breeding Company and was available, in addition to the water, *ad libitum* allowing maximum growth rate. Great care was taken to check the health condition of the chickens during their stay in the Animal House. Up to the age of 70 days birds survived without any sign of serious illness. After 70 days of age many birds gradually developed an inability to walk, or support themselves unaided due to weakness in the legs. This is a recognized problem with rapidly growing broiler chickens, and in an advanced condition is accompanied by breathing difficulty. Such birds were humanely killed and disposed of.

2.3 Carcass Analysis

All control and selected birds were weighed individually in the morning at weekly intervals starting from the first day for the control birds and 21 days for the selected birds.

Birds were sampled at 1, 10 (only for control birds), 20, 30, 40, 60, 70, 100 and 150 days. Sexual maturity is revealed by about 150 days. At each sample three healthy birds were chosen that were close to the general average live body weight. The individual live body weight and the mean weight of the three birds as a group at each age were recorded and plotted in graph.

Right and left pectoralis muscles were removed and the total wet muscle weight after removing any attached fat was recorded. A strip of muscle (approximately 10 $\times$20 $\times$ x mm, where x was the whole depth of the pectoralis muscle and was depended on age and region) was removed from between the insertion of the pectoralis muscle on the humerus (region A) and the origin towards the central portion of the pectoralis muscle (region B) (see figure 2.1, plate 2.1). These two regions correspond to the anterior (cranial), middle (caudal) section of the pectoralis muscles described by Papa and Fletcher (1988) and Smith and Fletcher (1988). I have always taken extra care to ensure that the strips of tissue were taken from similar places to avoid intramuscular variation in diameters and number of the fibre types. These tissues were frozen immediately for histochemical procedures. The remainder of all the pectoralis muscles were stored in deep freeze at -20^{o}C for further analysis of water contents (chapter VII).

Extensor Digitorum Longus (EDL) was also used for the histochemical staining methods as its structure is well known (see figure 4.2A, plate 4.2). This muscle was removed from the right leg and a small tissue sample was frozen and stored with the samples of pectoralis muscle.

Frozen sections were used to avoid dimensional changes due to histological processing (Gunn, 1976); and to differentiate the fibre types by using histochemical methods.

The following measurements were taken from the pectoralis muscle of the individual birds in each group:

2.3.1 Body Weight

Recorded to the nearest 1 g for first three weeks and then to 10 g in older birds.

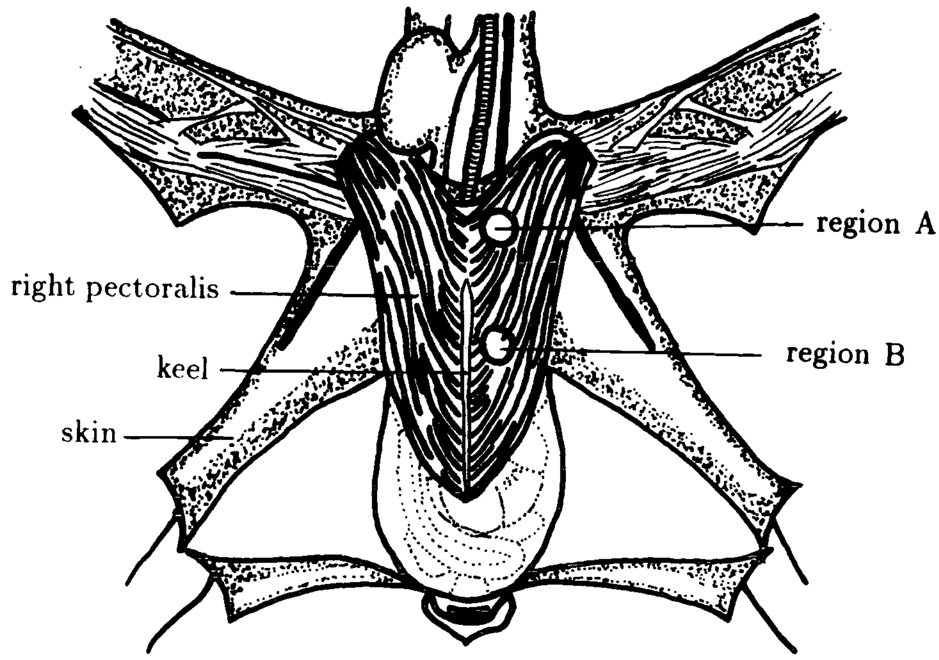

Figure 2.1 — Region A and Region B in Pectoralis Muscle

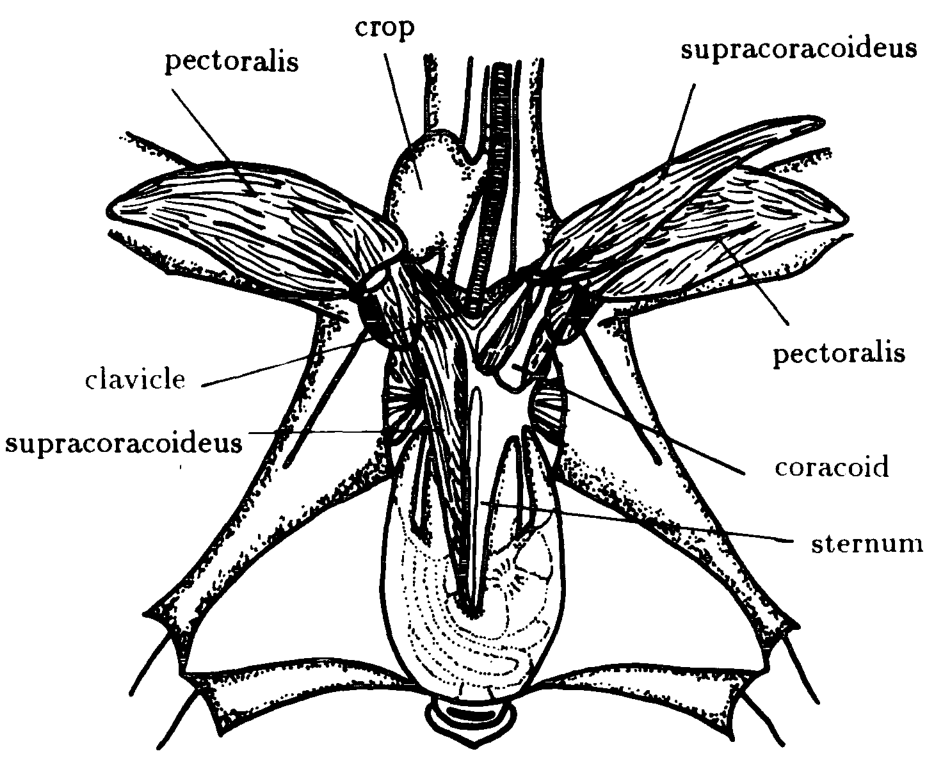

Figure 2.2 — Pectoralis and Supracoracoideus Muscles

Plate 2.1 — Pectoralis and Supracoracoideus Muscles in Brioler Chicken

Reproduce from Ede (1964)

2.3.2 Muscle Wet Weight

Pectoralis and supracoracoideus muscles (see figure 2.2, plate 2.1) were weighed by using an electric balance to the nearest 0.01 g. In chapter VI the maximum length (anterior-posterior) and the maximum width of the flattened pectoralis muscle was measured with callipers to the nearest 0.05 mm.

2.3.3 Fascicle Length

Pectoralis muscle fascicular lengths were directly measured by callipers to the nearest 0.05 mm. The longest and shortest fascicles inserted into corresponding area of the pectoralis muscle at each side of the pectoralis muscle were identified and their lengths were measured (see figure 2.10, plate 2.4).

2.3.4 The Skeleton

The next measurements were on the skeleton. After removing the pectoralis and supracoracoideus muscles from each side, the wings and legs were removal, then the trunk vertebrae, sternum and the pelvic girdle were left for further bone measurements. Most of the attached meat was removed, then the skeleton was boiled gently for 30-60 minutes. The skeleton was dried and the meat cleared off completely before any measurements were taken. The following bone measurements were made:

2.3.4.1 The Sternum (Figure 2.3, plate 2.2)

1) The total weight (including bone and cartilage), and keel bone weight (after removing the cartilaginous part of the keel) were recorded to the nearest 0.05 g.

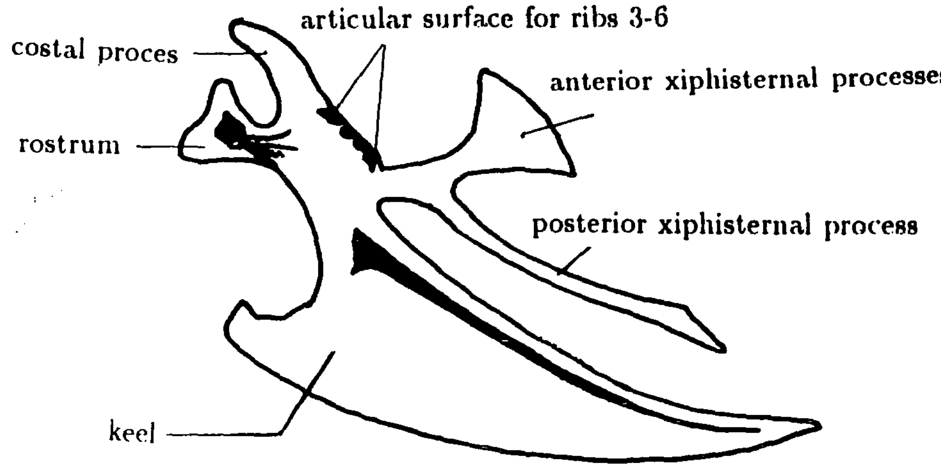

Figure 2.3 — The Sternum, Lateral View

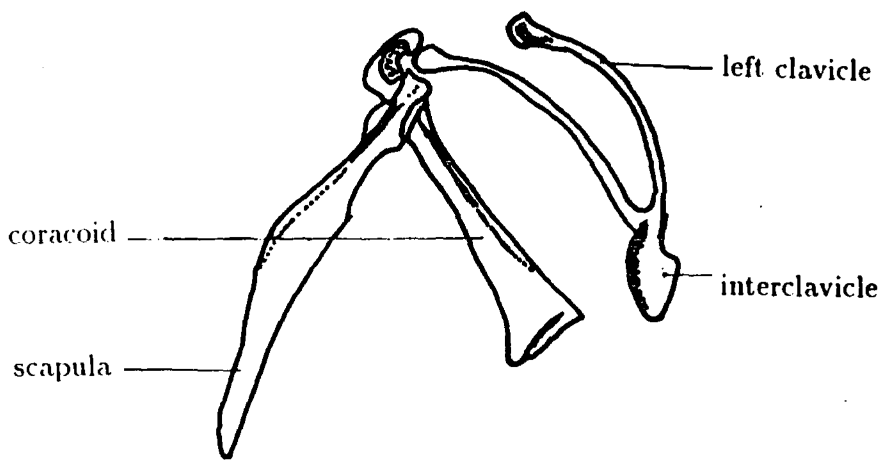

Figure 2.4 — The Pectoral Girdle

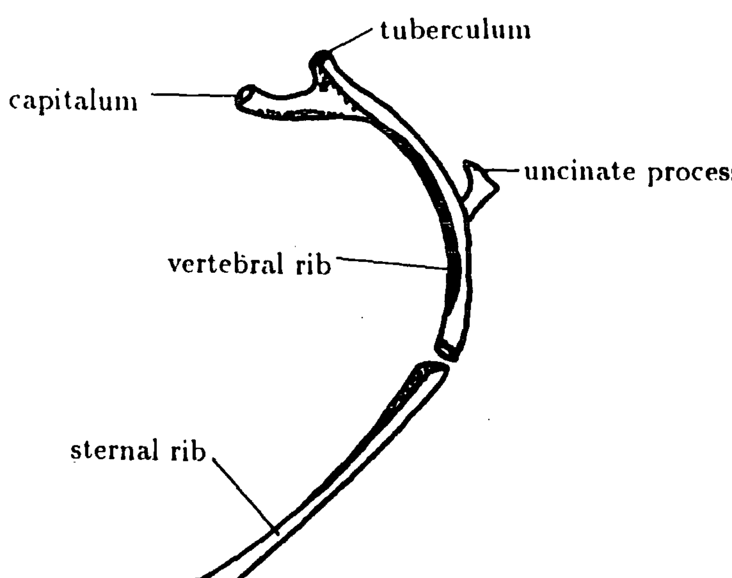

Figure 2.5 — A Thoracic Rib

Plate 2.2 — Skeletal Bones in Broiler Chicken

Reproduce from Ede (1964)

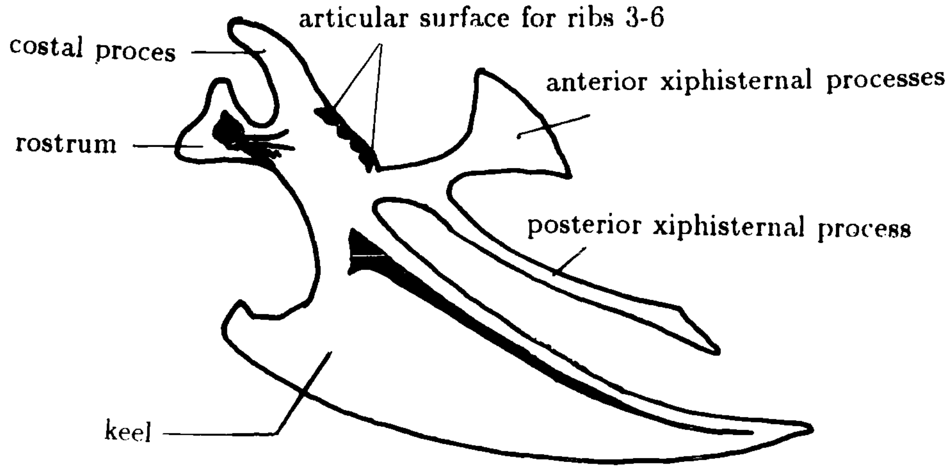

Figure 2.3 — The Sternum. Lateral View

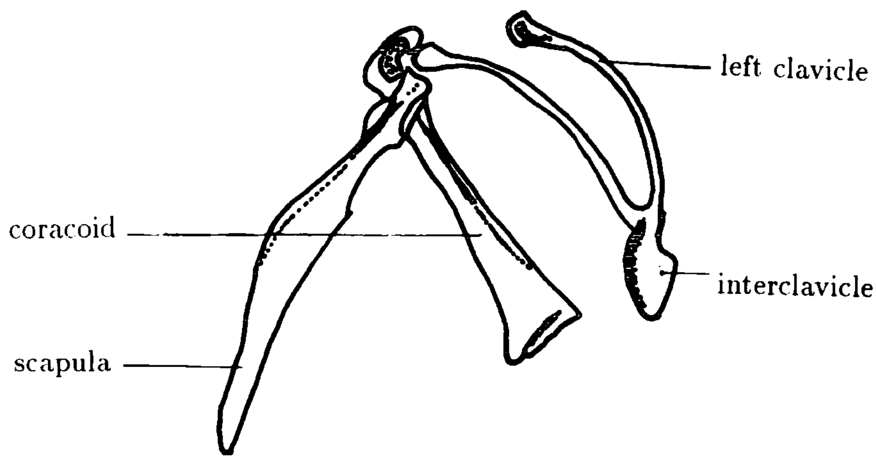

Figure 2.4 — The Pectoral Girdle

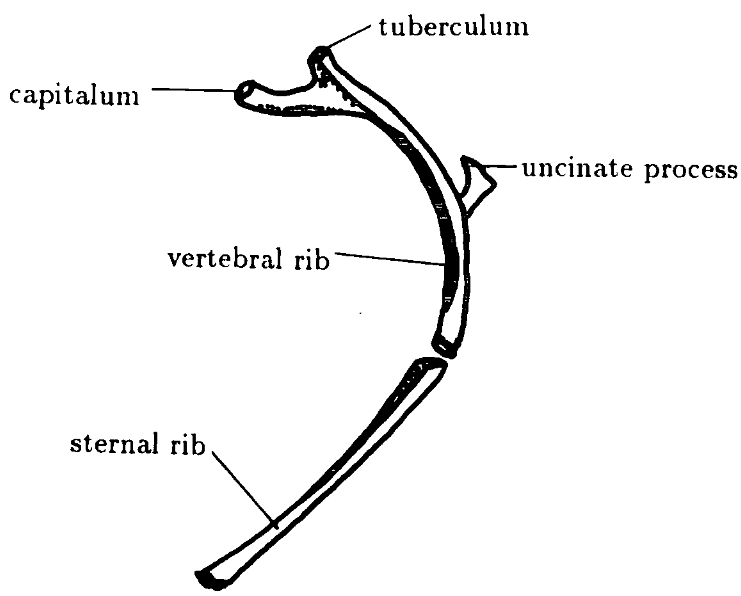

Figure 2.5 — A Thoracic Rib

Plate 2.2 — Skeletal Bones in Broiler Chicken

Reproduce from Ede (1964)

2) Total keel length from the cranial process of the crest to the caudal process of the body of the sternum, and the bone keel length were measured by callipers to the nearest 0.05 mm.

3) Keel height at the anterior side of the sternum (see figure 2.8, plate 2.3) was measured to the nearest 0.05 mm for the right and left sides where the posterior xiphisternal process (P.X process) joins the sternum.

4) Dorsal width of the sternum was measured to the nearest 0.05 mm where the posterior xiphisternal process (P.X. process) joins the sternum (figure 2.8, plate 2.3).

5) Keel depth of the right and left sides of the sternum was measured at the anterior end of the sternum (figure 2.8, plate 2.3).

6) Posterior and anterior xiphisternal process weight and length were measured to the nearest 0.01 g and 0.01mm respectively (figure 2.6, plate 2.3).

2.3.4.2 The Pectoral Girdle (Figure 2.4, plate 2.2)

Three bony elements in the *pectoral girdle* on each side (see figure 2.4, plate 2.2) were measured as follows:

1) clavicle bone: the clavicle bone was weighed and the lengths of the right and left parts were measured to the nearest 0.05 mm (see figure 2.7, plate 2.3).

2) coracoid bones: the weight and length of the right and left coracoid bones were measured to the nearest 0.01 g and 0.05 mm respectively.

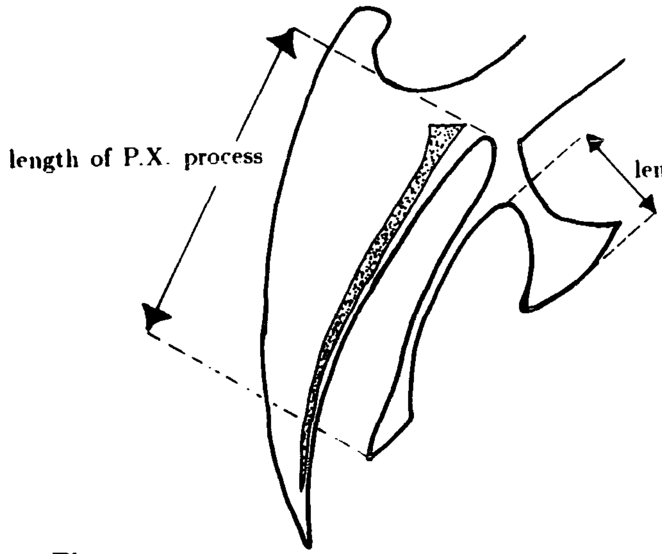

Figure 2.6 A. & P. X. process

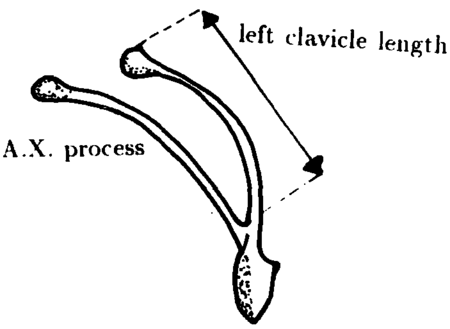

Figure 2.7 — Clavicle

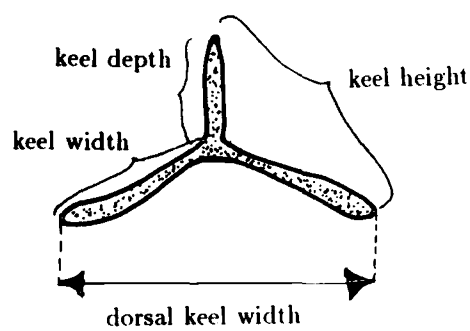

Figure 2.8 — Keel Cross-Section

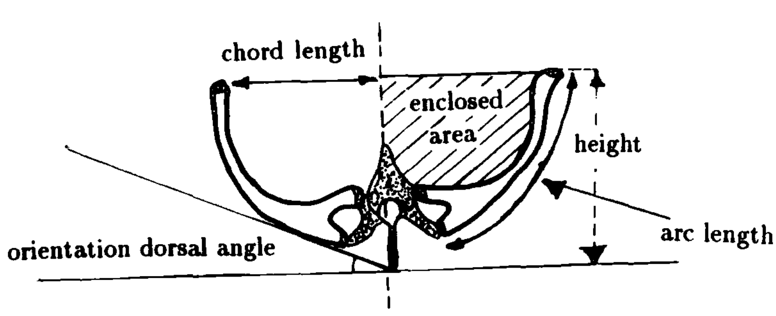

Figure 2.9 — Right and Left Ribs and the Caudal Vertebrae

Plate 2.3 — Measurements on Different Bones in the Broiler Chicken

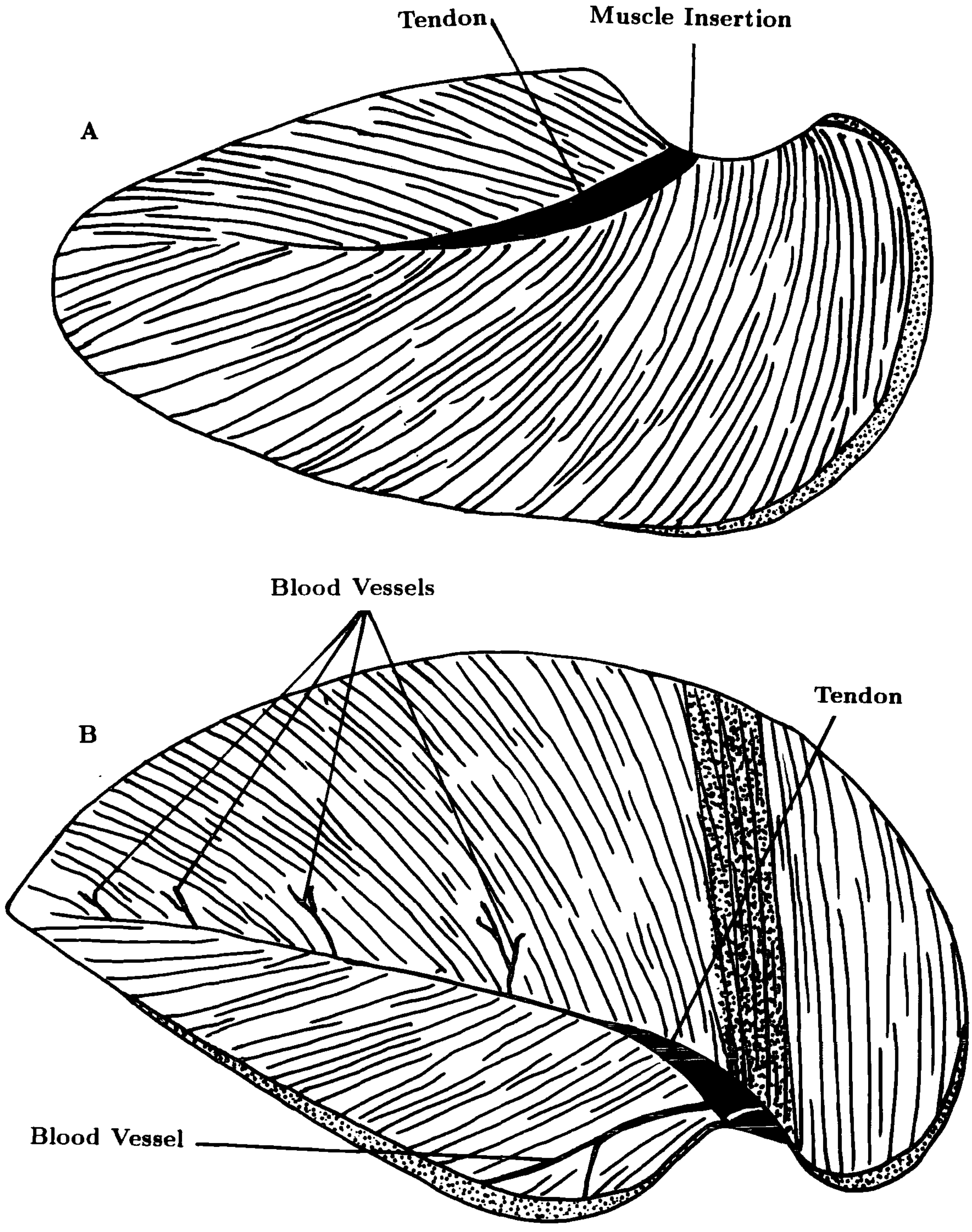

Figure 2.10 – Ventral (A) and dorsal (B) view of the flattend right pectoralis muscle in broiler chicken. The shaded area presents the chosen small area to measure fasciculi on the dorsal side in both right and left pectoralis muscle.

PLATE 2.4

3) scapula: length and weight were measured to the nearest 0.05 mm and 0.01 g respectively.

2.3.4.3 The Rib-Cage

After removing the pectoralis and supracoracoidious muscles, most of the attached meat was removed from the surface of the ribs, then the external angle of the rib-cage (breast angle) was measured on both sides. This angle was measured at the point where the ribs join the sternum at each side of the breast (see figure 2.11, plate 2.5). Then the skeleton was cooked in Automatic Fast Pressure Cooker (TOWER), at 15 lbs pressure for 5 minutes to ensure completed removed of soft tissues. After that the sternum and the ribs were cleared of meat and dried by paper tissue.

Extra care was taken when the ribs were disarticulated at the costovertebral joints and freed from adherent soft tissues. All the pairs of ribs from each bird were fixed on graph paper (see figure 7.9, plate 7.3), size A4, and photographed for further measurements. The following measurements were made:

A-) Intrinsic Measure (figure 2.9, plate 2.3)

Intrinsic measurements on the ribs were taken to examine the intrinsic shape symmetry (arc chord length and area) as described by Dansereau and Stokes (1988). The following data were obtained from each rib of the right and left side in each birds.

1) Arc length: Calculated as the total distance of straight-line segments between measured points on the rib. Distances between points were normally 5 mm up to a maximum of 10 mm depending on the curvature

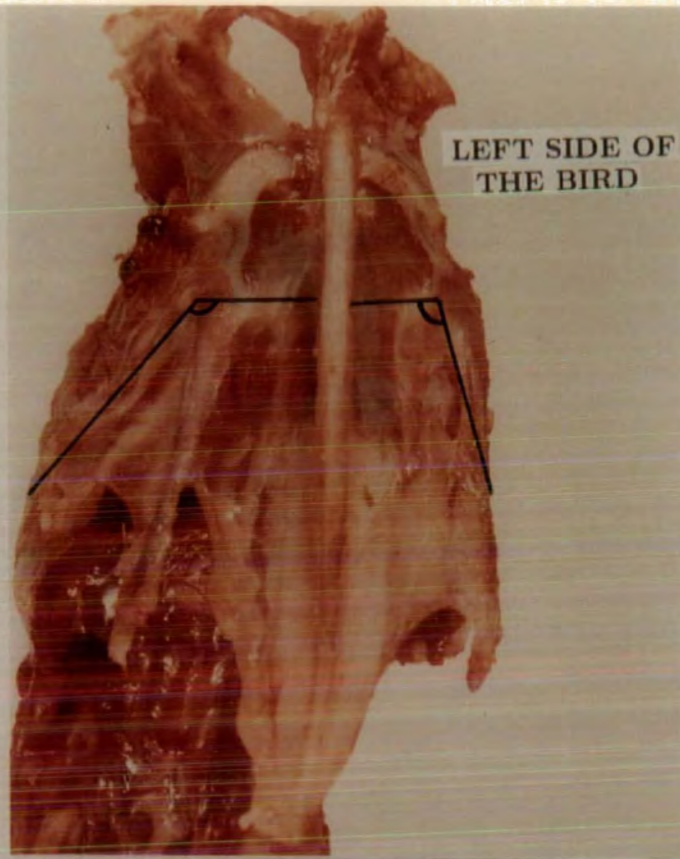

Figure 2.11 – Ventral view of the broiler sternum and rib-cage showing the location of measurement of the breast angle on the right and left sides.

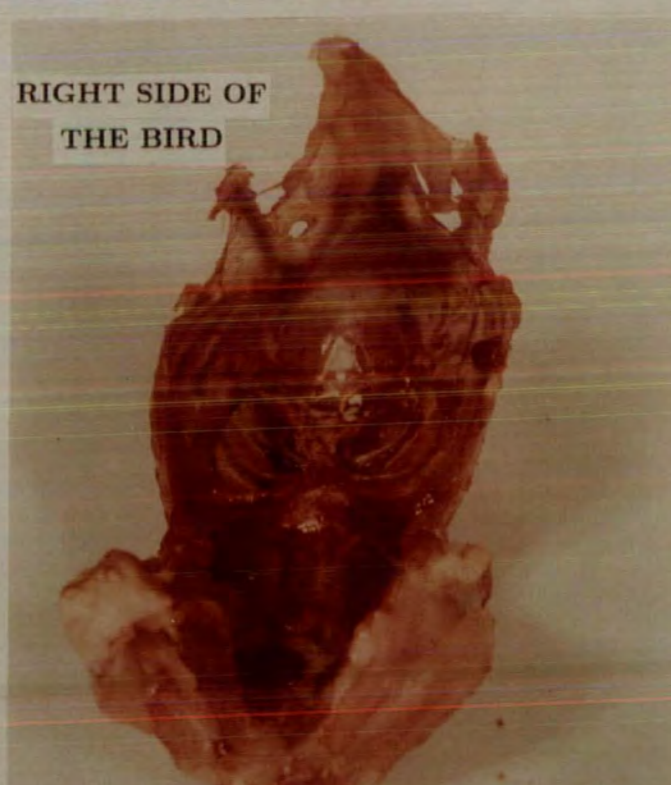

Figure 2.12 – Posterior view of the rib-cage in a selected chicken showing marked asymmetry.

Plate 2.5 — Sternum and Rib-Cage in the Broiler Chickens

of the rib.

2) Chord length: The straight distance between the costovertebral and costochondral joints.

4) Enclosed area (mm^2). The area bounded by the rib and the chord.

All these measurements were calculated with respect to a "best-fit plane" of the bony part (vertebral) of each rib at each side of the rib-cage, since it was found that the rib mid-line lay close to a flat plane.

B-) Extrinisic (orientation) measurement (figure 2.9, plate 2.3)

(1) Dorsal Rotation Angle: the measurement of rib orientation is the angle made by the best-fit plane of the vertebral rib to the horizontal line of the thoracic column (Dansereau, *et al.,* 1986).

C-) Length and Weight of the Ribs

Length of each rib (for both the sternal and vertebral parts) was measured along its outer surface. Then the weight of the two parts of each rib was taken separately to the nearest 0.01 g.

2.4 Histochemical Techniques

2.4.1 Tissue Sampling

The specimen of muscle was frozen as quickly as possible after its removal from the body to prevent the loss of soluble enzymes or the autolytic processes taking places which alter the localization and the activity of many enzymes in fresh tissue. It was the practice throughout this study to remove muscles and get the tissue samples into isopentane within 20-30 minutes.

2.4.2 Freezing the Tissue Samples

The simplest method is rapid immersion of the specimen into a coolant (cryogen). Here the physiochemical nature of the sample and its shape are as important as the speed factor. Other critical parameters are the physiochemical specification of the coolant and its minimum temperature, as determined in each case by its freezing point. The decisive factor in obtaining true-to-life vitrification of aqueous mixed phases seems to rely most of all on the freezing being as rapid as possible to avoid any damage to the cell components such as artefact formation which results from ice crystal formation and large holes are left in the tissue as a result of slow freezing rate. A freezing rate of over 10,000^{o}C/sec. can ensure good preservation of the native specimen (Sitte and Neumann, 1983) which before the freezing had no treatment with a fixing agent or a cryoprotection medium. Table (2.1) shows the list of most suitable coolant use in biological laboratories for freezing specimen.

When selecting a suitable coolant for immersion cryofixation the factors to consider beside the lowest possible freezing point, are above all, density, specific heat, viscosity and thermal conductivity. The boiling point should not be too low, since a low boiling point encourages the formation of an insulating gas envelope round the tissue sample (e.g. with liquid nitrogen), thus slowing the freezing rate. Therefore, liquid nitrogen should not be used for freezing tissue because of the very poor freezing rate. The best coolants for this reason are the propane and freon (and, recently, ethane) gases, but they have a higher specific gravity than air at room temperature and therefore carry a high risk of accumulation and explosion. Therefore, isopentane was chosen for this study which is also widely used in similar research work.

Chucks with the mounted specimens were immersed in the pre-cooled isopen-

Table 2.1 — List of Commonly Used Coolants for Freezing Biological Specimens

Coolant	Temperature at coolant surface	Freezing rate (°C/sec)
Propane	-190°C	98,000
Propane, Isopentane, Methylecyclohexane (20:5:1)	-191°C	96,000
Freon 13	-185°C	78,000
Freon 22	-155°C	66,000
Freon 12	-152°C	47,000
Isopentane	-160°C	45,000
Nitrogen, solid/liquid slush	-207°C	21,000
Liquid nitrogen	-196°C	16,000

Source: Costello and Corless (1978)

tane for 2-4 minutes (for large tissue samples) although this long period of immersion sometimes caused cracks which made sectioning more difficult, this would ensure the whole large tissue was frozen and avoid the production of freezing artefacts throughout the tissue due to ice crystal formation. After freezing the specimen was kept inside a tightly closed plastic bag in the cryostat at -20°C for sectioning on the following day.

2.4.3 Sectioning

A BRIGHT[1] Cryostat was used for tissue sectioning. CRYOMATRIX tissue

[1] Model FS/FCS/EC Clifton Road, Huntingdon, Cambs, England, PE18 7EU.

glue was cooled inside the cryostat for a while before using it to fix the frozen tissue on the chuck, then the tissue was trimmed to 10 × x mm section, where x is the depth of the muscle (here x will be the length of the section). The knife was firmly fixed at suitable angle to obtain good sections. Since the serial section thickness could be controlled from the clearance rotation angle this angle was set up before sectioning, by using specimen thickness and the toggle nut adjustments.

Frozen sections, 20μ thick, were cut and 2-4 serial sections were affixed to a slide (20 × 50 mm) for small sections of young chickens or to a slide (40 × 50 mm) for large sections of the older chickens. All sections were stored in the cryostat for 2-3 days before staining. For each histochemical method all the slides from each sample were incubated simultaneously. Slides from the three birds, including region A and B from both right and left pectoralis muscles, and the slide containing the EDL muscle sections were used. In this way it is possible to make direct comparison between the muscles, as any difference in staining intensity can be attributed to differences in the muscle and not to varying incubation conditions.

2.4.4 Histochemical Methods

The importance of the histochemical methods is to give a clear picture of the structure of the studied tissue. The purpose of using histochemical methods in this work was to study the structure of the pectoralis muscle on each side of the selected and control chickens. Any difference in fibre types between the right and left pectoralis muscles could indicate related metabolical and functional differences in the selected chickens.

There are many different histochemistry methods in standard textbooks. In this study the following methods were used:

2.4.4.1 Hydrolases

Representatively, hydrolases catalyse the following reaction:

$$AB + H_2O \rightleftharpoons AH + BOH$$

with hydrolism normally predominating.

The hydrolases can be divided into several groups, the most important group in histochemistry is the esterase which can be divided into various types. The carboxylesterases, phosphomonoesterases, phosphodiesterases and sulfatases.

In histochemical studies, the phosphomonoesterase type is widely used enzyme for histochemical demonstration in particular adenosine A (ATPase) and alkaline phosphatase (APPase). The following section gives a brief amount of these two enzyme.

- Adenosine Triphosphatases (ATPase)

ATPase catalyses the following reaction:

$$ATP + H_2O \rightleftharpoons ADP + Orthophosphate$$

Biochemical studies have revealed several adenosine triphosphatases in animal organs, which besides intracellular localization, show differences in relation to inhibitors. The most important adenosine triphosphatases are:

1- Myosin ATPase which is found in muscles; this enzyme has a pH optimum of 9 and is activated by calcium ions Ca^{2+}

2- Cell membrane ATPase, which is activated by sodium and potassium ions and requires magnesium ions for its function; the pH optimum is about 7.5

Both ATPases are responsible for the physiological degradation of adenosine triphosphate, i.e. they hydrolyse energy rich phosphate bonds with a release of energy.

3- Mitochonderial ATPase with various pH optimum and different behaviour in the presence of activitors.

All ATPases are relatively firmly bound to structures and are sensitive to fixation to varying degrees. The mitochonderial ATPase is the most sensitive one.

In this study the myosin ATPase is used where Ca^{2+} activates myosin ATPase reaction in the incubation medium at pH 9.4, 37^oC and employs preincubation with many modifications. The preincubation media is intended to allow differentiation between activities of the myosin ATPase from different fibres. Then, the incubation media activates the remaining active fibre with a release of phosphate forming calcium phosphate as is shown in the following formula:

$$C_3H_7O_3(ONa)_2 \longrightarrow C_3H_5(OH)_3 + Ca_3(Po_4)_2 \downarrow$$

The first component is the sodium salt of 2–glycerophosphate activated by myosin ATPase with H_2O and Ca^{2+}. The result of this reaction is the glycerin and Calcium Phosphate(white colour) respectively as shown above in the formula.

The sections are then reacted with aqueous Cobalt Chloride to give cobalt phosphate, as shown in the following formula:

$$Ca_3(Po_4)_2 + 3Co^{2+} \longrightarrow Co_3(Po_4)_2 \downarrow$$

On addition of aqueous ammonium sulphide the dark salt of cobalt sulphide is produced, as following:

$$Co_3(Po_4)_2 + 3S^{2-} \longrightarrow 3CoS$$

This reaction would stain up the active fibres light brown to black with inactive fibres remaining colourless.

- Myosin ATPase Method (Guth and Samaha,1970)

1) Solutions

A) Fixative (2 % Formalin buffered at pH 7.6)

a) Formaldehyde Solution(40%)................ 50 ml.

b) Na Cacodylate(MW 160)....................... 31 g.

c) $CaCl_2$ (MW 147) .... 10 g.

d) Sucrose (MW 342).................................115 g.

Bring to final volume of 1 litre with distilled water

B) Rinse solution [18mM $CaCl_2$ in 100mM tris(hydroxymethyl aminomethane), pH 7.8].

a) Tris(MW 121)...........................12.1g.

b) $CaCl_2$ (0.18M) ....100 ml.

c) Distilled water...........................900 ml.

adjust pH to 7.8 with HCl (1 to 6 N) using pH meter, and bring final volume to 1 litre with distilled water.

C) *[2] Alkaline preincubation (18mM $CaCl_2$ in 100mM buffer, pH 10.4).

a) Sigma No. 221[3] buffer (1.5M)........................3.35 ml.

b) $CaCl_2$ (0.18M)..100 ml.

c) Distilled water..40 ml.

adjust pH to 10.4 with KOH (1 to 10 N) using pH meter and bring final volume to 50 ml with distilled water.

D) * Incubation solution (2.7mM ATPase, 50mM KCl, 18mM $CaCl_2$ in 100mM buffer, pH 9.4).

a) Sigma No. 221 buffer (1.5 M).................3.35 ml.

b) $CaCl_2$ (0.18 M)..5.00 ml.

c) KCl (MW 75)......................................185.00 mg.

d) ATP, Disodium[4] (MW 551.2).................76.00 mg.

e) Distilled water ....40.00 ml.

Adjust pH to 9.4 with 6N HCl, using pH meter, and bring final volume to 50 ml with distilled water.

E) Wash solution (1% $CaCl_2$ w/v).

a) $CaCl_2$ (MW 147).........................10g.

b) Distilled water 1000ml

[2] All solution marked with * should be freshly made before use.

[3] Sigma No.221 buffer is a trade name for a 1.5M solution of 2-amino-2-methyle-1-propanol that is obtainable from Sigma Chemical Co.

[4] Obtainable from Sigma Chemical Supply Company.

F) * Cobalt chloride solution (2% w/v).

a) $CoCl_2$ (MW 238).......................1 g.

b) Distilled water ....50 ml.

G) * Alkaline washing solution (100mM buffer, pH 10.4).

a) Sigma No. 221 buffer(1.5M) ....13.4 ml.

b) Distilled water....................................160 ml.

Bring pH to 9.4 with HCl (1 to 6 N) using pH meter and adjust to final volume of 200 ml with distilled water.

H) * Ammonium sulphide solution (1% v/v).

a) Ammonium sulphide[5] ....0.5 ml.

b) Distilled water....................................50 ml.

This solution must be kept and used inside a fume cupboard.

I) * Acid preincubation solution (50mM potassium acetate, 18mM $CaCl_2$, pH 4.35).

a) $CaCl_2$ (0.18M)...........................100 ml.

b) Glacial acetic acid........................3 ml.

c) Distilled water..........................900 ml.

Adjust pH to 4.35 with KOH (1 to 5N) using pH meter and bring final volume to 1000 ml with distilled water.

[5] This reagent deteriorates with age. It should be replaced if mottled, uneven staining of the tissue section occurs

2) Procedure for Alkali–stabile ATPase:

a) Dry frozen sections for 30 - 60 minutes at room temperature.

b) Fix sections for 5 minutes in solution *a*.

c) Rinse slides in solution *b* for 1 minute, with agitation, and drain excess solution on blotting paper.

d) Preincubate in solution *c* for 15 minutes.

e) Rinse slides in solution *b* (two changes, 1 minute each) and drain excess solution.

f) Incubate for 15 - 60 minutes in solution *d* at 37°C.

g) Wash in three 30-seconds changes of solution *e* and drain excess solution.

h) Place in solution *f* for 3 minutes.

i) Wash in four 30-seconds changes of solution *g* and drain excess solution.

j) Place in solution *h* for 3 minutes.

k) Wash in running water for 3 - 5 minutes.

l) Dehydrate in 70%, 95% and absolute alcohol, clear in xylene and mount in DPX.

The stain is permanent and slides could be stored at room temperature.

3) Procedure of Acid–stabile ATPase:

a) Dry frozen section for 30 - 60 minutes at room temperature.

b) Preincubate the unfixed sections in solution *(i)* for 3-50 minutes; then drain excess solution.

c) Complete the preparation as per steps *e* - *l* above.

Note: Do not incubate slides that have been preincubated in acid or alkali in the same jar of incubation solution.

2.4.4.2 Oxidative Enzymes (Dehydrogenases)

Histochemically detectable dehydrogenases can be divided into *coenzyme-independent* i.e. dehydrogenases that do not require nicotinamide dinucleotide (NAD^+; formerly DPN, diphosphopyridine) or nicotinamide adenine dinucleotide phosphate ($NADP^+$; formely TPN, triphosphopyridine nucleotide), and *coenzyme-dependent* dehydrogenases, which transfer hydrogen to coenzyme NAD^+ and $NADP^+$.

The most elementary of the oxidative enzyme reactions is the NADH-tetrazolium reductase (NADH-TR) reaction (synonym NADH dehydrogenase, or in old terminology DPNH-diaphorase). The tetrazolium reductases are found in the mitochondria and endoplasmic reticulum and are relatively firmly (but not absolutely) structure-bound. In enzyme histochemistry tetrazolium reductases give information on the capacity for intracellular oxidation. NADH-TR frequently serves as a marker enzyme of mitochondria. Moreover, tetrazolium reductases participate in the detection of coenzyme-dependent dehydrogenase when phenazine methosulphate (**PMS**) is not present. This is apparent in two ways:

1- The tetrazolium reductases determine the localization of the dehydrogenase under investigation, i.e. in the detection of dehydrogenase by classic methods without PMS the corresponding tetrazolium reductase is localized, and not the dehydrogenase in question.

2- The tetrazolium reductases can limit the dehydrogenase reaction since they mediate between the reduced coenzyme and the acceptor, for instance, Nitro-BT (the direct reduction of tetrazolium salts by reduced coenzyme at pH 7.2–7.6 is inefficient and thus insignificant). For this reason, at sites with low activities of tetrazolium reductase the dehydrogenase can be only inadequately demonstrated by procedures without PMS; therefore, artifacts result. In order to avoid a weak display of activity in white fibres of the striated muscles, where the NADH-TR reaction is weak, PMS is added as an artificial mediator to the incubation medium.

The principal of the histochemical demonstration of the oxidative enzymes is to employ a colourless, soluble tetrazolium salt which intercepts the electron at some point along the respiratory chain and is reduced to a deeply coloured, insoluble product. A commonly used tetrazolium salt, and the one used in this study as well is Nitro-BT[6].

Details of routinely used histochemical oxidative enzyme methods may be found in standard textbooks on the subject including, Davenport (1964); Pearse (1972); Dubowitz and Brooke (1973); and Lodja, *et al.,* (1979).

- NADH-Tetrazolium Reductase (Pearse, 1972 *pp.* 1342-1343).

  1- Solutions:

    a-) Stock 0.2M buffer, pH 7.4:

      Solution A: 0.2M Tris (hydroxymethyl) aminomethane (24.2g/litre).

[6] Obtainable from Sigma Chemical Supply Company

Solution B: 0.1N HCl (38% assay) 86 ml/litre.

To 25 ml solution A, 42.5 ml of solution B added. Make up to 100 ml by adding distilled water.

2- Stock Incubation Solution:

a-) Nitro-BT (4mg/ml) ....75 ml

b-) Tris buffer (pH 7.4) ....75 ml

c-) Magnesium chloride (0.005M); (0.1g/100ml)........30 ml

d-) Distilled water ....90 ml

The pH is adjusted to 7.0 - 7.2 using stock 0.2M tris or 0.1M HCl solution. This stock incubation solution stored at -20°C to -25°C until use.

3- Incubation Solution

a-) Stock incubation solution................................270 ml

b-) Distilled water...30 ml

c-) NADH coenzyme..0.6 g

The NADH coenzyme was added just before use and the pH checked and adjusted to 7.0-7.2.

4- Procedure:

a-) Dry sections for 15 - 30 minutes at room temperature.

b-) Incubate sections in the incubating solution for 30-45 minutes at 37°C.

c-) Pour off the incubating solution and immerse sections in 15% formal saline for 15 minutes.

d-) Wash in running water for 2 minutes.

e-) Rinse well in distilled water.

f-) Dehydrate in 70%, 95%, and absolute alcohol; clear in xylene and mount in DPX.

The use of alcohol for dehydration will cause some decrease in intensity of the stain, but it is not an essential step and could be omitted for the sake of removal of fat, and to improve the quality of the sections.

2.4.4.3 Glycolytic Enzymes (Transferases)

These enzymes catalyse the transfer of certain groups from one compound to another. The reaction follows the following general pattern:

$$RD + A \rightleftharpoons RA + D$$

Some of these enzymes could be detected by histochemical methods, such as glycogen phosphorylase, the 1,4-α-glucan branching enzyme that build up the branching of glucan, and for glycogen syntheses. Since the histochemical detection of the phosphorylase and branching enzyme is performed by the same method the two will be dealt with together.

In vivo, phosphorylase is located in high concentrations in the cytoplasm of anaerobic tissue and is concerned with hydrolysis 1,4-α-glucosidic linkages. *In vitro*, on the other hand, it catalyses the reverse reaction of D-glucose-1-phosphate to glycogen as shown in the following equation:

$$(1,4-\alpha-Glycosyle)_{n-1}+D-glucose-1-phosphate \longrightarrow Orthophosphate+$$

$$(1,4-\alpha-D-Glucosyle)$$

This reaction depends on pH . At low pH it is shifted to the left, i.e., glucosyl residues are transfered to the glycosyl chain, the so-called primer. There are two forms of phosphorylase in animal tissue(Lodja, *et al*, 1979) phosphorylase *a* (or phosphophosphorylase) which is an active form, and the other form is called phosphorylase *b* (or dephospho-phosphorylase). The second form, phosphorylase *b* , can be activated to the first form by phosphorylase kinase. Phosphorylase kinase is activated by adrenaline and glycogen. The detection of the maximum glycogen phosphorylase activity requires adenosine monophosphate(AMP). The histochemical techniques depends on the synthesis of polysaccharide chains from glucose-1-phosphate. The length of these chains is proportional to the activity of phosphorylase present, and when stained by iodine the colour will vary according to the chain length. High activity would give chains with 30-35 glycosyl units, staining deep blue; less activity 20-30 units staining light blue, reddish shades indicate 8-12 units; yellow-white, 4-6 units ; as described by Swanson (1948). Synthesis of branched polysaccharides of glycogen or amylopectin requires an additional enzyme, branching enzyme or amylo-1,4-6-transglucosidease (Cori and Cori, 1943). Inhibitation of the branching enzyme can be effected using methanol, magnesium and manganese ions or mercuric chloride ($HgCl_2$, 0.1 mM) in the incubation medium.

Details of staining methods of glycolytic enzymes such as phosphorylase (and for substances such as muscle fibre glycogen and lipid) could be found in standard textbooks of histochemistry which are mentioned above.

The details of the histochemical procedures employed in the identification of glycolytic enzyme activity in the investigation reported in this thesis are given below:

- Phosphorylase Method (Lodja, *et al.*, 1979, *p* 218; after Takeuchi and Kuriaki (1955); Takeuchi (1958); Erañkö and Palkama (1961); and Godlewski (1963).

A- Incubation Medium

a- Distilled water ....180 ml.

Add successively in the following order:

b- Glucose-1-phosphate, sodium salt ....0.6 g.

c- Adenosine-5′-monophosphate, sodium salt.........................0.12 g.

d- Ethylenediamine tetraacetic acid, sodium salt (EDTA)..0.24 g.

e- Sodium fluoride ....0.24 g.

f- Glycogen, water-soluble..0.12 g.

g- Insulin.

Insulin addition to the incubation medium was used by Takeuchi and Kuriaki(1955) to accelerate the phosphorylase reaction, or to enhance the phosphorylase activity (Barka and Anderson, 1963); however this has not been confirmed by Lodja, *et al.*, (1979) and I found similar results with and without insulin, therefore, the addition of insulin was omitted in this research work.

h- 0.1M Acetate buffer, pH = 5.8............................120 ml.

i- Polyvinylpyrrolidone(PVP), mol wt. 25,000.......18 g.

(Phosphorylase and the branching enzyme can exert their activity without the presence of (PVP). This substance suppresses the diffusion of preexisting glycogen which act as a primer, and of phosphorylase. Therefore, the final staining is more intense and distinct when (PVP) is used).

The incubation medium should be prepared just before use and mixes very well, the pH should be checked after mixing and adjusted to 5.8 if necessary.

2- Lugol's Iodine:

a- Iodine..1 g.

b- Potassium iodide...................................2 g.

c- Distilled water..................................300 ml.

This solution can be prepared and stored in the fridge in a dark bottle.

3- Procedure :

a- Dry sections at room temperature for 15 minutes.

b- Incubate for 30 minutes at 37^{o}C.

c- Pour off incubation medium and rinse in distilled water.

e- Place in 70% and 95% alcohol for 1 minute each.

f- Make sure the sections are dry before the next step.

g- Place in diluted Lugol's solution (1:9) for 3-5 minutes (until colour is developed).

h- Rinse in distilled water.

i- Place in 4% formaldehyde for 5 minutes.

j- Rinse in distilled water.

a- Dehydrate in 70%, 95% and 100% tertiary butanol, clear in xylene, mount in DPX.

Although this procedure is meant to be a permanent preparation (Lodja, *et al.*, 1979), I found the sections were faded slightly within two weeks and completely after a month. Therefore photographs were taken as soon as the sections were dried.

2.5 Muscle Fibre Types

Many types of investigation have been performed on skeletal muscles so that clear distinctions can be made between the multiple fibre types which can be present. In the case of mammalian muscles, these fibre types have been well defined in a variety of studies, and are commonly classified into convenient categories such as those of Brooke and Kaiser (1970), i.e., types I, IIA, IIB, on the basis of the characteristics summarised in table 2.2. However, no single fibre typing system devised for mammals has been shown to cover the range of types present in the muscles of birds (or the other classes of vertebrates). Some systems which have been used (Shafiq, *et al.,* 1971; Ashmore and Doerr, 1971; Brook and Kaiser, 1974; Khan, 1976; and Barnard *et al.*, 1982) for avian muscles are essentially the same as the above mentioned system for mammalian classification. In general, mature avian skeletal muscle fibres are broadly classified as fast- twitch glycolytic fibres (FG or white fibres) or slow oxidative fibres (SO or red), on the basis of morphological, physiological and biochemical characteristics (Chandra-Bose and George, 1965; Padykula and Gauthier, 1967; Johnston, 1985; and Rosser and

Table 2.2 — Comparison of Different Fibre Types in Avian Muscles

Classification	Avian Muscle Fibres		
Fibre Types:	1	2	3
(1)Brooke and Kaiser (1970, 1974) (2) Barnard, *et al.*, (1982)	IIB	I	IIA
(3) Khan (1976)	II White	I Red	II Red
(4) Padykula and Gauthier (1967) (5) Chandra-Bose and George (1965)	White	Intermediate	Red
(6) Ashmore and Doerr (1971)	αW	β	αR
(7) Peter, *et al.*, (1972)	FG	SO	FOG
Histochemical Criteria:			
Glycolytic Actvity (Romanul, 1964)	High	Low	Intermediate
Oxidative Enzyme Activities (Barnard,*et al.*, 1982)	Low	High	Intermediate
Mitochondrial ATPase (Gauthier, 1969)	Low	Intermediate	High
Myofibrillar ATPase at pH = 9.4 (Barnard *et al.*, 1982)	High	Low	High
Phosphorylase (Barnard *et al.*, 1982)	High to intermediate	Low	High to intermediate

George, $1986_{a,b}$).

The characterisation of the three main fibre types is shown in table 2.2 and could be summarised as follows:

1- White (FG) fibres show low oxidative enzyme activities (NADH-TR), high glycolytic activity (phosphorylase) and low mitochondrial ATPase. These fibres are adapted for intense, brief, bursts of activity.

2- Red (SO) fibres have high oxidative enzyme activities (NADH-TR), low glycolytic activity (phosphorylase) intermediate mitochondrial ATPase and low myofibrillar ATPase at pH 9.4.

3- Intermediate (FOG) fibres appear to have intermediate activities and characteristics between the FG and SO fibres.

The purpose of using histochemicl methods in to study the main structural differences between the pectoralis muscle on the right and left side of both control and selected birds. The techniques used not only allow the identification of the different fibre types but also the fibre diameters can be measured and their numbers counted. This study would indicate whether there is any differences in the muscle structure or not, and, as a result, relate this difference(s) to physiological, morphological or genetical causes.

2.5.1 Number and Diameter of Pectoralis Muscle Fibres

Two regions from both the right and left pectoralis muscle have been chosen as shown in figure 2.1 (plate 2.1). Particular care was taken to ensure that the tissue preparation was similar on both sides of each bird. All sections from the three birds in each group were incubated together so that direct comparison of reaction intensity could be made. By measuring the number and diameter of the different fibre types present in each region, it can be seen if there are any differences within different areas of the same muscle, as well as between the right and left sides.

The classification scheme used here follows that of Peter *et al.*, (1972), distinguishing slow-twitch oxidative (SO), fast-twitch oxidative-glycolytic (FOG), and fast-twitch glycolytic (FG) fibres on the basis of oxidative enzyme activity (NADH-TR).

Many different measurements of fibre size have been employed by different laboratories (e.g. Sissons, 1965; Adams, *et al.*, 1968; Dubowitz and Brook, 1973; and Ishihara and Araki, 1988)

The method felt to be the most reliable index of muscle fibre number and size is the measurement of the average fibre diameter (maximum + minimum diameter/2) according to Sissons (1965), Ishihara and Araki (1988).

Since the pectoralis muscle is large, different in size at each side (for selected birds), and heterogeneous in fibre structure, i.e., the fibre types distributed differently in different regions, for example superficial surface muscle consists almost entirely of fast-twitch fibres (FG and FOG) whereas the anterior deep surface has more SO fibres (Rosser and George 1966b), therefore the method of counting and measuring the fibres was very important. It was decided to count the fibre types from each microscopic field by projection onto a screen using a Leitz Microprojector.

In pectoralis muscle of chicken, the anterior deep surface of the muscle has been called the "Red" region by Gauthier and Lowey (1977), because there are relatively more red(SO) fibres than in the superficial surface "White" region. These two regions have been defined by above authors as follows:

> A conspicuous "red" region is present at the anterior deep surface of the pectoralis. It forms a circumscribed band of fibres which extend from the ventral towards the dorsal border of the muscle. The "white" region is defined here as a small triangular portion of the pectoralis formed by cutting parallel to the tendon of insertion in a posterior direction towards the tip of the sternum, then parallel to the sternum in an anterior direction, and finally along the posterior border of the anterior red band.

In this study, region A and B represent the "Red" and "White" regions respectively as described in the above definition and shown in figure 2.1, plate 2.1.

Fibre type counting always began at the deep red side of the pectoralis muscle (close to the sternum) and the microscopic field was moved sequentially site by site across the muscle belly (section) until the last microscopic field at the superficial side. All the fibres of each type were counted from all microscopic fields and the mean number of each fibre type per square millimeter was calculated for each microscopic field, then the average number was calculated for all microscopic fields using the computer program (1) in appendix A.

Number of the microscopic fields was depended upon the thickness of the muscle and this not only differed between birds of different ages, but also in the same bird there may be a difference between the right and left sides and between the different regions in the same muscle of the bird.

Fibre diameter was measured only from the first 3-4 microscopic fields starting from the deep red side in order to measure all the three fibre types in that area because SO fibres do not appear in the later microscopic fields towards the superficial side. 2-4 myofibrils (a band of fibres) were chosen randomly and the diameter of all the fibres of each type within these chosen myofibrils were measured.

2.5.2 Calculation

The maximum and minimum diameter of individual fibres were was measured by callipers on the projection screen to the nearest 0.5mm. The magnification was also recorded for each microscopic field. The collected data were fed to a computer program (2) in appendix A to calculate mean, standard deviation, standard error and coefficient of variance of diameter for each fibre type for each bird. The results are presented in appendix C. The overall mean of fibre-type diameter for each group of age (three birds) was calculated by computer program (3) in appendix A using the data from the three birds. The results are presented in chapters IV and V.

The number of fibres was counted from all the microscopic fields in each region. The diameter of the microscopic field was measured by calliper on the projection screen to the nearest 0.5mm, and recorded with the magnification value. Collected data were used for the computer programme (1) in appendix A to calculate the mean, standard deviation, standard error, and coefficient of variance, for number of each fibre types per square millimeter (mm^{-2}).

2.6 Ultrasonic Machine

It was thought by Cobb Breeding Company at the beginning of this work that some birds show asymmetrical growth in the breast. These birds were identified at age 20 days by skilled handlers at Cobb Breeding Company. However, the results from chapter III and IV revealed no asymmetrical differences between the right and left sides of pectoralis muscle in the selected chickens that were identified by hand. Therefore, it was necessary to find a different method to of identify those birds which show breast asymmetry for the purpose of this study. As a result , an ultrasonic machine (SCANO ULTRASONIC SCANOPROB II, model 731C) was used to select chickens showing pectoralis asymmetry at age 50 days rather than 20 days.

Anatomical and histochemical studies were applied at age 50 and 100 days on chickens selected for pectoralis asymmetry. This study is presented in Chapter V. More chickens selected by ultrasonic technique for skeletal asymmetry were used for studying the growth and development of the keel and rib-cage. The results of this study are presented in chapter VII.

2.7 Statistical Methods

The means of live body weight, muscle wet weight, bone measurements (weight and length), number and diameter of pectoralis muscle fibres, for control and selected chickens, were calculated using a simple statistical program (1) and (2) in appendix A. A *pooled* estimate of variance (σ^2) was calculated using the following formula (Mead and Curnow, 1983):

$$\sigma^2 = \frac{(n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2}{(n_1 - 1) + (n_2 - 1)}$$

Where σ_1^2 and σ_2^2 are the variances of the first and second population respectively, and n_1 and n_2 denote number of the first and second population respectively. Then for the particular test of the hypothesis that the two samples come from populations with the same mean, Student's t- was calculated as follows:

$$t = \frac{(\overline{X}_1 - \overline{X}_2)}{\sqrt{\sigma^2(\frac{1}{n_1} + \frac{1}{n_2})}}$$

and compared with the various levels of significance point of the t- distribution with $(n_1 + n_2 - 2)$ degree of freedom.

In addition to the above basic statistics, regression statistics were used for many variables against different dependents. Logarithmic transformation of the raw data were undertaken when it seemed appropriate. In analysing growth patterns the data were fitted by least-squares regression to the well known allometric growth equation (Huxley, 1932). This equation described a simple mathematical method for the detection of the *allometric growth* of animal tissues. Allometry is the study of relative growth (of changes) in proportion to increase in size (Henderson,*et al.,* 1966). In order to compare the relative growth of two components, they are plotted logarithmically on X and Y axes:

$$Y = aX^b$$

$$logY = loga + blogX$$

The slope of the resulting regression is called the *allometric growth ratio,* or growth coefficient, often designated as b (or k). With b = 1, both components are growing at the same rate. With b < 1, the component represented on the Y axis is growing more slowly than the component on the X axis. With b > 1, the Y axis component is growing faster than the X- axis component.

Student's t-test was used to test whether the slope of the regression line relating X and Y differed from 0, by using the following equation:

$$t = \frac{(b-0)}{s.e.(b)}$$

This Student's t-test is exactly equivalent to the F-test which shown in table 2.3. Degree of significance was given in the statistical analysis tables.

When Student's t-test was significantly different from 0, the strength of the

Table 2.3 — Analysis of Variance

Source of Variance	s.s.	d.f.	m.s.	F-test
Regression		1	s.s./d.f.	m.s.(reg.)/m.s.(res.)
Residual		n−2	m.s/(n−2) = s^2	
Total		n−1		

relation between X and Y was tested using Student's t-test as follows:

$$t = \frac{(b - z)}{s.e.(b)}$$

Where:

z = 3 if Y= weight against X= length

z = 1 if Y= weight against X= weight

z = 0.333 if Y= fibre diameter against X= weight

z = 0.666 if Y= fibre number against X= weight

Different values of z were derived respectively from the following formulas:

$$M \propto L^3$$

$$M \propto M$$

$$D \propto M^{\frac{-1}{3}}$$

$$N \propto M^{\frac{-2}{3}}$$

Where M is the mass (or weight), L is the length, D = diameter, and N = Number of fibre.

Analysis of variance was used to study the regression relationships between features on the right and left sides within a bird, or between one side of the control chickens and its corresponding side in the selected birds. By this mean, it could be determined whether the relationships differ significantly or not.

To do this analysis of variance, the linear regression methods give the equations of the two lines to be compared. The result from the first set of data would be

$$b_1 = \frac{\Sigma(X_1Y_1) - \Sigma(X_1)\,\Sigma(Y_1)/n_1}{\Sigma(X_1^2) - [\Sigma(X_1)]^2/n_1}$$

$$a_1 = \frac{\Sigma(Y_1) - b\,\Sigma(X_1)}{n_1}$$

So, Residual Sum of Square RSS_1 could be calculated as follows:

$$RSS_1 = \sum(Y_1^2) - \frac{(\sum Y_1)^2}{n_1} - \frac{(S_{xy})_1^2}{(S_{xx})_1}$$

Similarly for b_2, a_2 and RSS_2.

To test whether the two relationships are the same or not, F-test was followed to investigate the possibility that the two sets of data differ in the linear relationships. So, comparison between the residual variation about the two individual fitted lines were made. If the two sets of data have the same linear relationships, a single regression line could fit the two sets of data. Hence the slope of the single line could be calculated as follows:

$$b = \frac{\Sigma(X_1Y_1) + \Sigma(X_2Y_2) - [\Sigma(X_1) + \Sigma(X_2][\Sigma(Y_1) + \Sigma(Y_2)]/(n_1 + n_2)}{[\Sigma(Y_1^2)\,\Sigma(X_2^2)] - [\Sigma(X_1) + \Sigma(X_2)]^2/(n1 + n2)}$$

or , writing $\sum(X)$ instead of $\sum(X_1) + \sum(X_2)$, etc.

Table 2.4 — The Relationship of the Analysis of Variance

Analysis of Variance	s.s.	d.f.	m.s.	F-test
Residual Variation for set 1	RSS_1	$n_1 - 2$		
Residual Variation for set 2	RSS_2	$n_1 - 2$		
Residual variation about a single lines	RSS	$n_1 + n_2 - 2$		
Sum of residual variation for individual lines	$RSS_1 + RSS_2$	$n_1 + n_2 - 4$	s^2	
Difference of slopes	$RSS - (RSS_1 + RSS_2)$	2		F†

†The significance of F-test indicates that the two relationships are not the same and a single line could not fit the two sets of data, without identifiying where the difference occur.

$$b = \frac{\Sigma(XY) - \Sigma(X)\Sigma(Y)/n}{\Sigma(X^2) - [\Sigma(X)]^2/n}$$

$$a = \frac{\Sigma(Y) - b\Sigma(X)}{n}$$

and the sum of square is

$$RSS = \sum(Y^2) - \frac{[\Sigma(Y)]^2}{n} - \frac{(S_{xy})^2}{S_{xx}}$$

The RSS has ($n_1 + n_2 - 2$) degrees of freedom for the residual variation.

F-test was calculated as follows (table 2.4):

$$F = \frac{[RSS - (RSS_1 + RSS_2)]/2}{s^2}$$

If the difference was small compared with s^2 then the two sets of data are the same and their slopes are parallel, otherwise, if the difference was large (i.e.

F-test significant), then the two sets of data have different linear regressions and the slopes of the two relationships are not parallel or had different intercepts. Furthermore, Student's t-test was followed when the F-test was significant to test whether the regression coefficient of the two relationships are the same or not, as follows:

$$t = \frac{(b_1 - b_2)}{\sqrt{b_{\sigma^2}(\frac{1}{n_1} + \frac{1}{n_2})}}$$

and compared with significance point of the t- distribution with $(n_1 + n_2 - 2)$ d.f. If the Student's t-test of the slopes of the two relationships was not significant, this implied that the regression relationships had the same slopes but different intercepts. But if the Student's t-test was significantly different, this would give evidence that the two slopes are not identical and one regression slope could not fit the two data.

CHAPTER III

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Chapter III

GROWTH AND DEVELOPMENT OF THE MAJOR TISSUES IN CONTROL AND SELECTED GROUPS OF CHICKENS

3.1 Introduction

3.1.1 Growth and Development of Animals

In general, growth may be considered as a combination of processes such as increase in cell number (hyperplasia) and in cell size (hypertrophy) until mature body weight is attained. These changes involve differential growth of various organs and tissues so that the animal develops and displays net change in shape.

In animal production, growth rate of the whole animal or its commercially relevant parts is important in determining economic efficiency (Fowler and Livingstone, 1972). A fast-growing animal would involve less labour and overhead cost per kilogram of product than a slower growing animal. However carcass measurements would be required to express adequately the true economics of producing an animal with fast growth rate.

3.1.2 Measurement and Expression of the Growth

Growth can be measured in various ways. The type of measurement used should depend on the intended use of the animal.

For meat animals intended for slaughter, the growth measurement should provide an indication of the edible portion of the carcass that meets minimum quality standards, such as lean meat and that portion of the fat that may be consumed.

To describe growth fully, data on both size and rate of growth are required. Average weight (W), growth rate (GR), and percentile growth rate (PGR) measurements were used in this study.

Most producers measure growth rate of animals destined for slaughter as:

$$GR = \frac{W2-W1}{t2-t1}$$

Where *W1* is the weight at *t1*, the end of a sampling period. *W2* is the weight at *t2*, the end of the subsequent period. In this study the growth rate of the body weight of individuals of the two populations, i.e. control and selected chickens, was calculated each week by recording the live weight for individual birds. In addition to the absolute growth rate, a percentile growth rate was calculated as follows:

$$PGR\% = \frac{W2-W1}{W1} \times 100$$

Poultry for slaughter are marketed at standard weights following a relatively short growing period so that growth rate is recorded as the number of days to reach market weight. However, this measure provides little indication of the value of the carcass, as some parts of it are inedible and growth rate varies in the different tissues and organs of the body (Hammond, 1932). Therefore, the growth of the edible part of the body would be of great value for the breeding selection programme.

Huxley (1932) described a simple mathematical method for the detection of the *allometric growth ratio* of animal tissues. Allometry is the study of relative growth (of changes) in proportion to increase in size (Henderson,*et al.,* 1966). In order to compare the relative growth of two components, they are plotted logarithmically on X and Y axes (see Chapter II, p.59).

3.1.3 Growth and Development of Chickens

Recent growth data on broiler chickens beyond the common slaughter age of 49 days are very limited (Lewis, 1985), since in commercial broiler chicken production, birds of approximately 2.4 kg. body weight are slaughtered. However, over the past 40 years the trend in the broiler industry has been to increase the growth rate of broiler chickens (see table 3.1). This has come about as a result of genetic and nutritional developments. As a result of this acceleration of body growth, some problems have emerged as side effects to the selection for heavy body weight, or high growth rate, e.g. leg weakness, increased fattiness. The purpose of this chapter is to describe development and growth of the main body tissues in both control and selected chickens.

3.2 Live Body Weight (LBW)

3.2.1 Increase in Live Body Weight with Age

The increase in LBW from hatching (in control birds) or 21 days (in selected birds) to 147 days of age is shown in table 3.2 and figure 3.1. The growth curves of LBW for control and selected chickens appear to be approximately sigmoid or logistic, although the asymptote had not been reached at 147 days as shown in

Table 3.1 — Percentage Increase in Body Weight of Male Broiler Chickens in 2-Week Periods Between 1 and 56 Days of Age

	Year*				
Age(days)	1952(a)	1978(b)	1980(c)	1985(d)	1989(e)
1	–	–	–	–	–
14	171	614	763	769	886
28	99	176	139	194	181
42	100	66	88	80	77
56	65	51	42	44	44

* (a) Wilson, (1952)

(b) Summers and Leeson (1979)

(c) Leeson and Summers (1980)

(d) Cobb Breeding Company (1985)

(e) Cobb Breeding Company (1989a)

figure 3.1. Selected chickens were significantly heavier than corresponding control chickens as has been indicated in table 3.2 and shown in figure 3.1, except at the early age (i.e. 21 days) when the selected chickens arrived in Durham.

Table 3.2 — Live Body Weight from Hatching to 147 Days Post-Hatching in Control and Selected Broiler Chickens

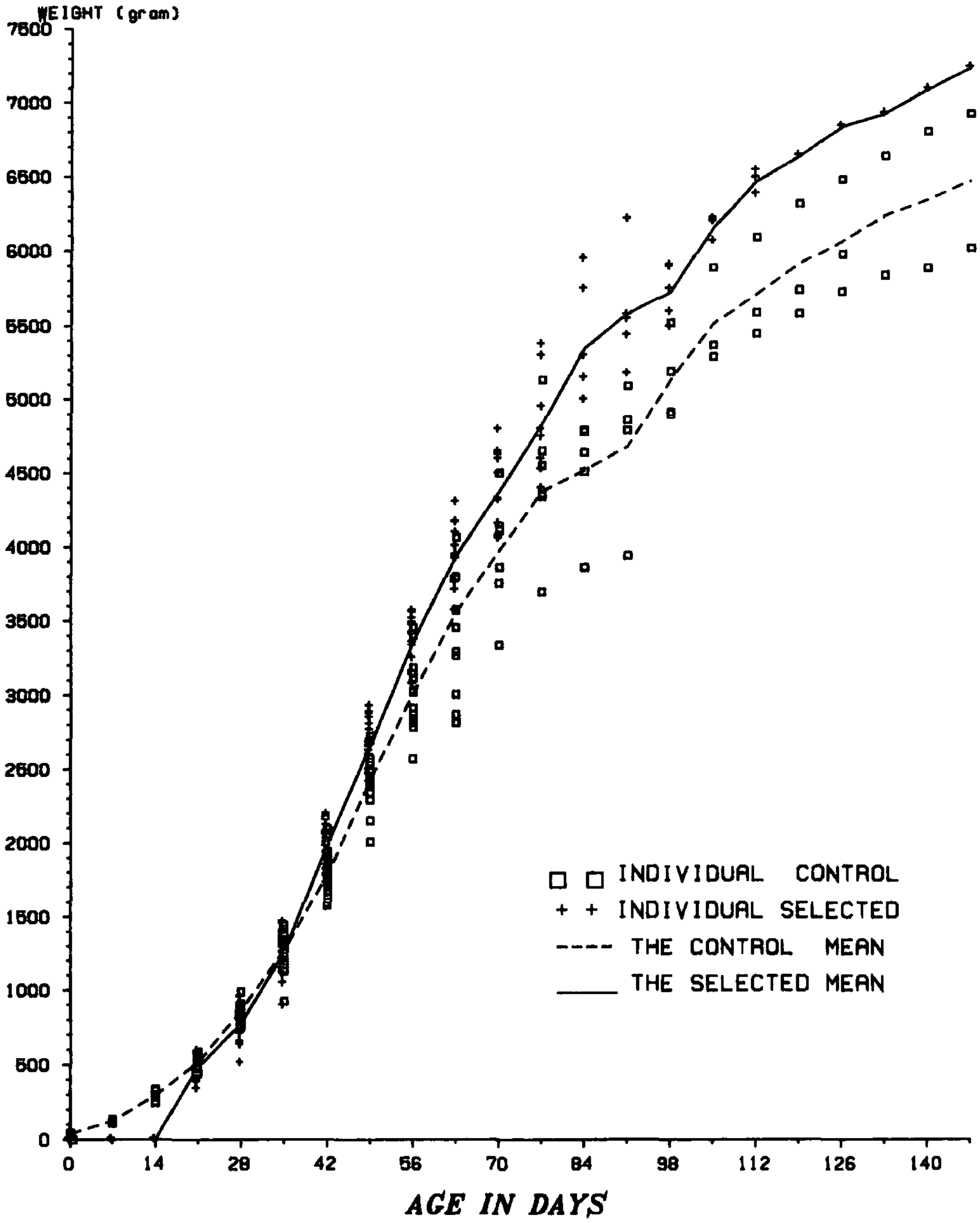
(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Control Chickens Mean (g) ± SE	Selected Chickens Mean (g) ± SE	Significance of Difference‡
1	19/0	39.67 ± 0.723	-	-
7	16/0	123.76 ± 1.745	-	-
14	13/0	293.69 ± 7.494	-	-
21	10/34	514.00 ± 12.668	483.06 ± 9.923	N.S.
28	10/31	861.30 ± 21.240	774.36 ± 16.903	N.S.
35	22/28	1270.82 ± 18.655	1256.00 ± 24.819	N.S.
42	18/23	1785.44 ± 34.205	1990.43 ± 29.471	4.62***
49	17/20	2426.41 ± 42.424	2663.95 ± 36.533	4.27***
56	13/16	3015.00 ± 69.565	3358.94 ± 39.998	4.77***
63	11/12	3557.09 ± 110.609	3946.75 ± 62.839	3.13**
70	7/11	3982.86 ± 139.892	4380.91 ± 81.123	2.65*
77	5/8	4384.17 ± 175.321	4838.75 ± 124.804	2.24*
84	5/8	4526.00 ± 171.833	5356.25 ± 120.431	4.08**
91	4/5	4690.00 ± 253.410	5594.00 ± 171.627	3.06*
98	4/5	5140.00 ± 146.345	5732.00 ± 81.080	3.75**
105	3/5	5526.67 ± 188.089	6166.67 ± 37.705	3.29*
112	3/3	5720.00 ± 194.249	6480.00 ± 47.256	3.80*
119	3/1	5925.00 ± 157.732	6650.00	-
126	3/1	6075.00 ± 222.055	6850.00	-
133	2/1	6252.20 ± 402.499	6940.00	-
140	2/1	6360.09 ± 460.001	7110.00	-
147	2/1	6485.00 ± 455.002	7255.00	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between the control and selected chickens.

FIGURE 3.1 – LIVE BODY WEIGHT IN CONTROL AND SELECTED CHICKENS



3.2.2 Growth Rate of Live Body Weight

The growth rate of selected chickens at age 28 days was lower than control chickens. This was probably a result of transferring the former from the Cobb Breeding Company in Essex to Durham at age 20 days, and could be a consequence of transportation which may affect growth rates, as has been reported by Acker (1983). However, selected chickens subsequently had a higher growth rate than control chickens, as shown in table 3.3 and figure 3.2. The highest growth rate of control and selected chickens was at 49 and 42 days respectively.

3.2.3 Percentile Growth Rate

As a result of high absolute growth rate in selected chickens, the percentile growth rate of the live body weight was also higher than in control chickens as shown in table 3.4.

3.2.4 Relative Growth of Live Body Weight With Age

Since there were insufficient collected data to study the *allometric growth ratio* of the body weight and many other measurements in the period prior to the maximum growth rate at 49 days, I decided to study the *allometric growth ratio* of the live body weight in two periods, the first one from the hatching date until 70 days, and the second period from 77 days to 147 days, approximating to the periods of accelerating and decelerating growth. For the other carcass components, the *allometric growth ratio* was calculated for only the first period.

Regression statistics for log LBW versus log age in days were calculated and the data are given in table 3.5.

Table 3.3 — Growth Rate (Absolute) of the Live Body Weight from Hatching to 147 Days Post-hatching in Control and Selected Broiler Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Control Chickens Mean (g/w) ± SE	Selected Chickens Mean (g/w) ± SE	Significance of Difference‡
1	19/0	-	-	-
7	16/0	84.04 ± 1.533	-	-
14	13/0	169.45 ± 6.759	-	-
21	10/34	220.20 ± 6.442	-	-
28	10/31	347.30 ± 10.869	286.25 ± 8.149	3.90^{***}
35	22/28	443.14 ± 11.133	472.57 ± 11.496	N.S.
42	18/23	510.44 ± 18.272	715.74 ± 14.471	8.93^{***}
49	17/20	629.94 ± 21.641	663.70 ± 16.909	N.S.
56	13/16	564.54 ± 36.663	674.88 ± 17.852	2.87^{***}
63	11/12	563.73 ± 48.649	565.15 ± 31.679	N.S.
70	7/11	464.71 ± 37.245	443.40 ± 17.524	N.S.
77	5/8	484.00 ± 40.571	463.75 ± 51.856	N.S.
84	5/8	198.00 ± 29.900	517.50 ± 45.580	5.07^{***}
91	4/5	227.50 ± 65.365	314.00 ± 51.630	N.S.
98	4/5	222.50 ± 93.215	298.00 ± 30.232	N.S.
105	3/5	313.33 ± 66.915	313.33 ± 7.187	N.S.
112	3/3	193.33 ± 17.638	313.33 ± 7.187	6.02^{*}
119	3/1	171.67 ± 29.485	260.00	-
126	3/1	183.33 ± 28.914	200.00	-
133	2/1	135.00 ± 24.996	190.00	-
140	2/1	107.51 ± 57.502	170.00	-
147	2/1	125.00 ± 4.999	145.00	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the t-test between the control and selected chickens.

FIGURE 3.2 - GROWTH RATE OF LIVE BODY WEIGHT IN
CONTROL AND SELECTED CHICKENS

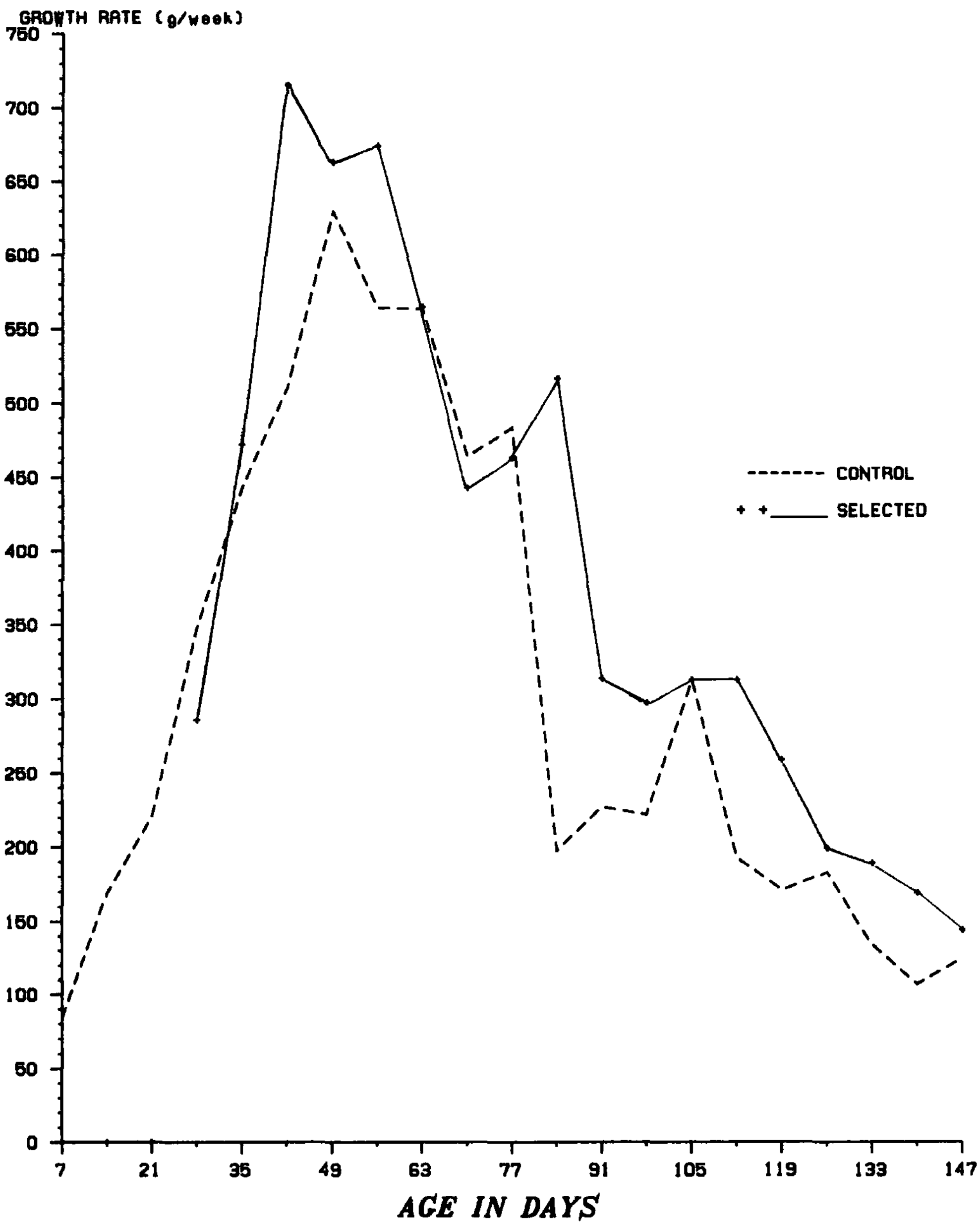


Table 3.4 — Growth Rate, as a Percentage of the Live Body Weight, from Hatching to 147 Days Post-hatching in Control and Selected Broiler Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Control Chickens Mean (% weekly) ± SE	Selected Chickens Mean (% weekly) ± SE	Significance of Difference‡
1	19/0	–	–	-
7	16/0	213.32 ± 5.748	–	–
14	13/0	114.98 ± 5.106	–	–
21	10/34	76.17 ± 2.546	–	–
28	10/31	67.65 ± 1.676	58.70 ± 1.243	3.74***
35	22/28	53.74 ± 1.418	60.80 ± 1.572	3.25**
42	18/23	40.03 ± 1.219	56.29 ± 1.122	9.95***
49	17/20	35.22 ± 1.356	33.32 ± 0.975	N.S.
56	13/16	22.82 ± 1.306	25.35 ± 0.773	N.S.
63	11/12	18.78 ± 1.547	17.48 ± 0.667	N.S.
70	7/11	13.30 ± 1.141	10.93 ± 0.561	2.22*
77	5/8	12.66 ± 0.854	10.58 ± 1.117	N.S.
84	5/8	4.59 ± 0.684	10.79 ± 1.043	4.31**
91	4/5	5.09 ± 1.260	6.00 ± 1.069	N.S.
98	4/5	5.65 ± 2.070	5.48 ± 0.550	N.S.
105	3/5	6.03 ± 1.334	5.36 ± 0.143	N.S.
112	3/3	3.50 ± 0.312	5.08 ± 0.167	4.49**
119	3/1	3.57 ± 0.583	4.07	-
126	3/1	2.53 ± 0.007	3.01	-
133	2/1	2.19 ± 0.276	2.81	-
140	2/1	2.09 ± 0.382	2.45	-
147	2/1	1.98 ± 0.219	2.04	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the t-test between the control and selected chickens.

Table 3.5 — Regression Analysis of Live Body Weight of the Control and Selected Chickens Against Age

Age(days)	Birds	Y- Intercept a	Growth Coefficient b ± SE	R^2	F-test C vs. S	t-test C vs. S
1 – 70	Control	0.815	1.498*** † ± 0.038	0.944		
20 – 70	Selected	0.136	1.926*** ± 0.070	0.992	8.96**	5.65***
77 – 147	Control	2.401	0.657*** ± 0.035	0.975		
77 – 147	Selected	2.552	0.609*** ± 0.032	0.976	81.78***	N.S.

† Degree of significance of difference from 1 of the growth coeffiecent.

The growth coefficient for LBW of both control and selected chickens with age in both periods was very significantly different from one, as indicted in table 3.5. Moreover, the *allometric growth ratio* of the selected chickens was not equal or parallel to that the control chickens in the first period (b = 1.926 , F =8.959 p < 0.01, t = 5.65 p < 0.001) as shown in table 3.5, therefore the slopes of the two sets of data in the first period were different as shown in table 3.5 and figure 3.3 (in figure 3.3, the control chickens slope for the period 20 to 70 days rather than the calculated slope in table 3.5). The analysis of variance of the live body weight of the control and selected chickens in the second period revealed that the slopes of the two regression lines were not significantly different, i.e. they were parallel as shown in table 3.5 and figure 3.4. However, the two sets of data were significantly different (F = 81.779, p< 0.001).

Figure 3.3: Regression Line of the LBW in Control and Selected Chickens (20–70 Days)

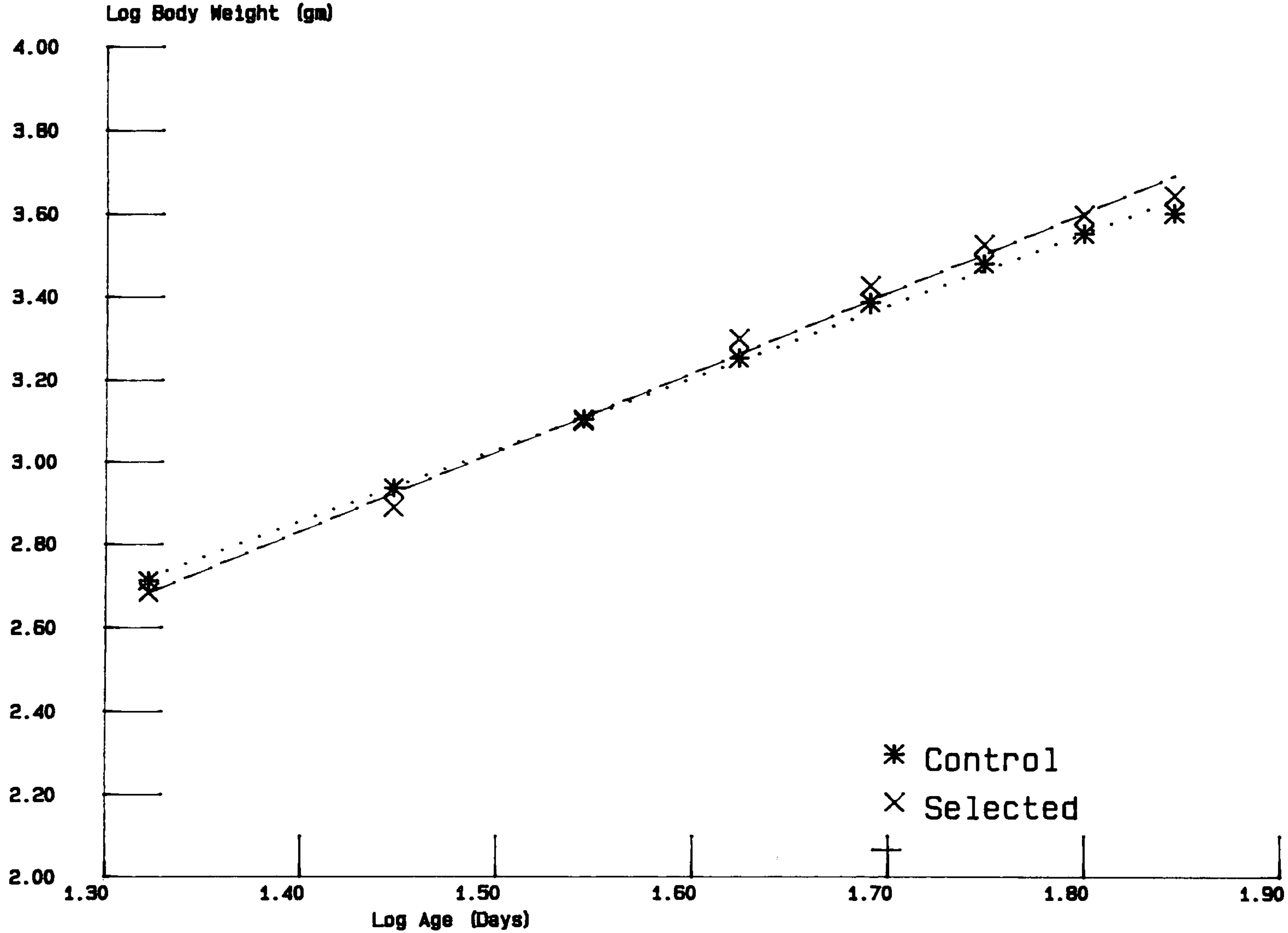
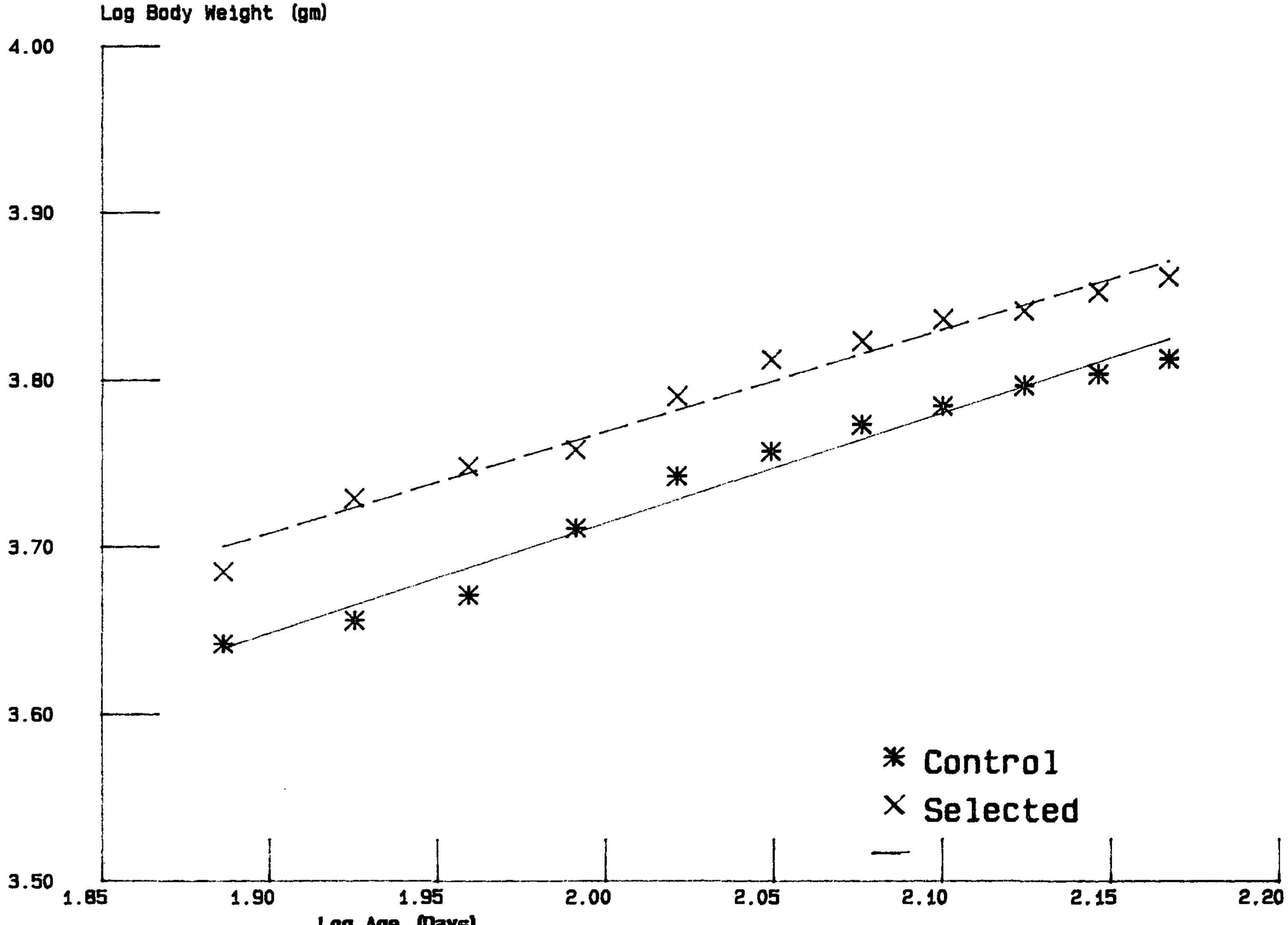


Figure 3.4: Regression Line of the LBW in Control and Selected Chickens (77–147 Days)



The conclusion from the above analysis of the live body weight changes was that selected chickens were growing faster in the first period than the control chickens, whereas in the second period both chickens groups were growing at a similar rate so that selected chickens were heavier in live body weight in that period, i.e. from 77 to 150 days.

3.3 Pectoralis Muscle

3.3.1 Absolute Wet Weight of Pectoralis Muscle

The mean wet weight of pectoralis muscle in both control and selected chickens is given for each age in table 3.6, and the data are plotted in figures 3.5A and 3.6A. There were no significant differences between the weight of right and left sides of pectoralis muscle in control or selected chickens. Although selected chickens had significantly heavier live body weights than control chickens, there was no significant difference between corresponding pectoralis muscles of the right or left sides as shown in figures 3.7A and 3.7C.

3.3.2 Growth Rate of Pectoralis Muscle

The growth rate of pectoralis muscle in control and selected chickens is presented in table 3.7, and the data are plotted in figure 3.8. A similar result to the absolute wet weight was obtained in that control and selected chickens showed hardly any significant differences in growth rate between the right and the left pectoralis muscle. Moreover, Student's t-test was carried out between the right in the control and the right in selected chickens or the left in control to the left in

Table 3.6 — Pectoralis Muscle Weight from Hatching to 147 Days Post-Hatching in Control and Selected Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (g) ± SE	Selected Chickens Mean (g) ± SE	Significance of Difference‡
1	3/0	R	0.380 ± 0.098	–	-
		L	0.368 ± 0.087	–	
10	3/0	R	7.317 ± 0.759	–	-
		L	7.360 ± 0.815	–	
20	3/3	R	18.453 ± 2.248	17.683 ± 2.098	N.S.
		L	18.440 ± 2.140	18.730 ± 2.491	N.S.
30	3/2	R	45.773 ± 1.084	40.130 ± 1.590	3.077*
		L	46.613 ± 0.355	42.610 ± 2.715	N.S.
40	3/3	R	77.020 ± 6.293	71.820 ± 12.336	N.S.
		L	80.930 ± 7.309	77.517 ± 15.837	N.S.
50	3/3	R	134.637 ± 10.198	149.180 ± 8.175	N.S.
		L	139.090 ± 9.868	158.060 ± 6.842	N.S.
60	3/3	R	210.237 ± 19.670	211.693 ± 8.644	N.S.
		L	216.627 ± 22.504	220.323 ± 7.636	N.S.
70	3/3	R	281.933 ± 18.280	271.800 ± 18.702	N.S.
		L	296.463 ± 21.394	279.173 ± 17.217	N.S.
100	3/3	R	361.040 ± 21.990	374.120 ± 20.081	N.S.
		L	367.167 ± 25.450	404.637 ± 13.675	N.S.
150	3/1	R	464.480 ± 9.940	492.220	-
		L	494.785 ± 18.385	521.255	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between each side in the control chickens to its corresponding one in the selected chickens.

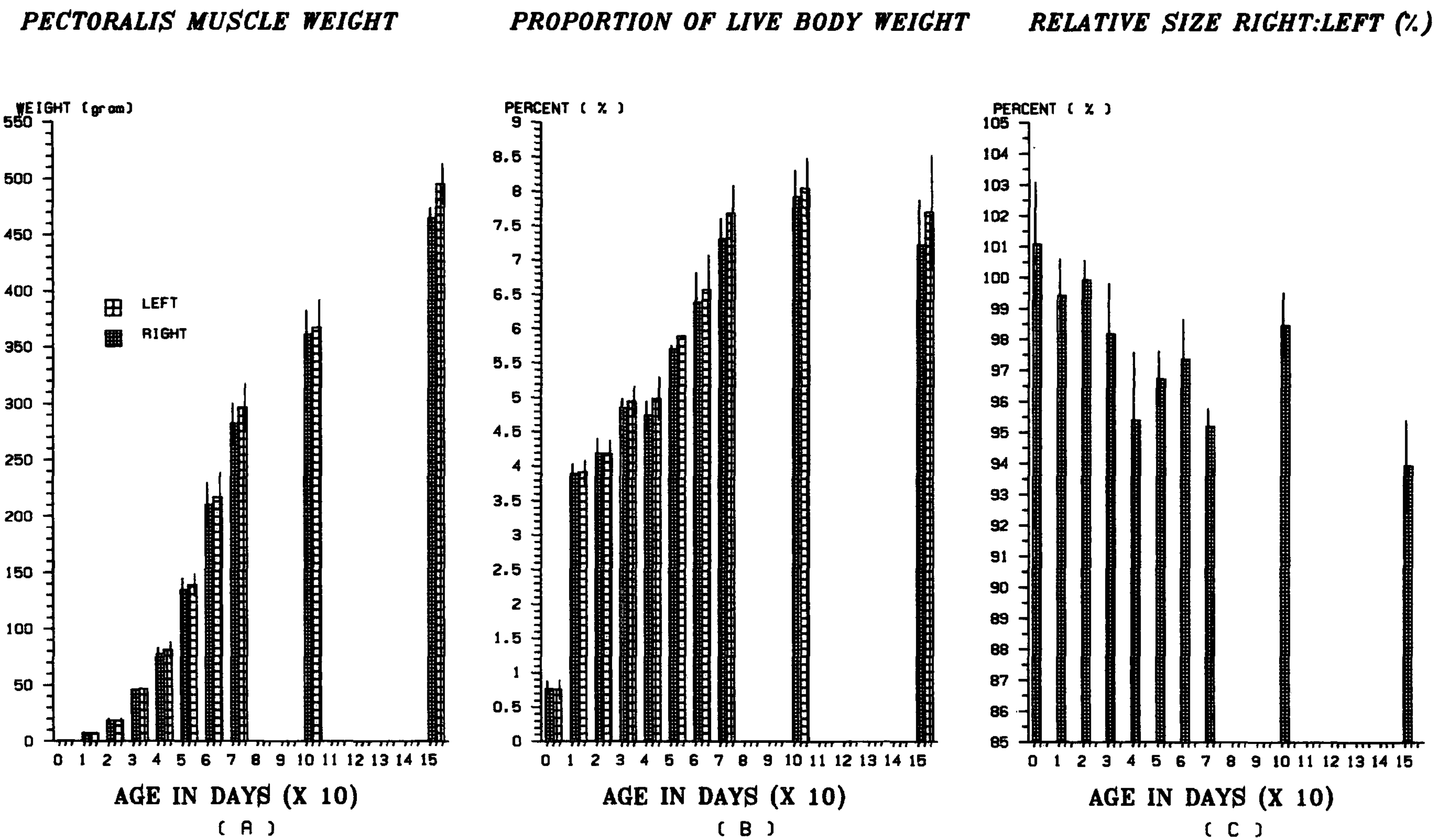


FIGURE 3.5 – PECTORALIS MUSCLE IN CONTROL CHICKENS
(OVERALL MEAN WITH STANDARD ERROR)

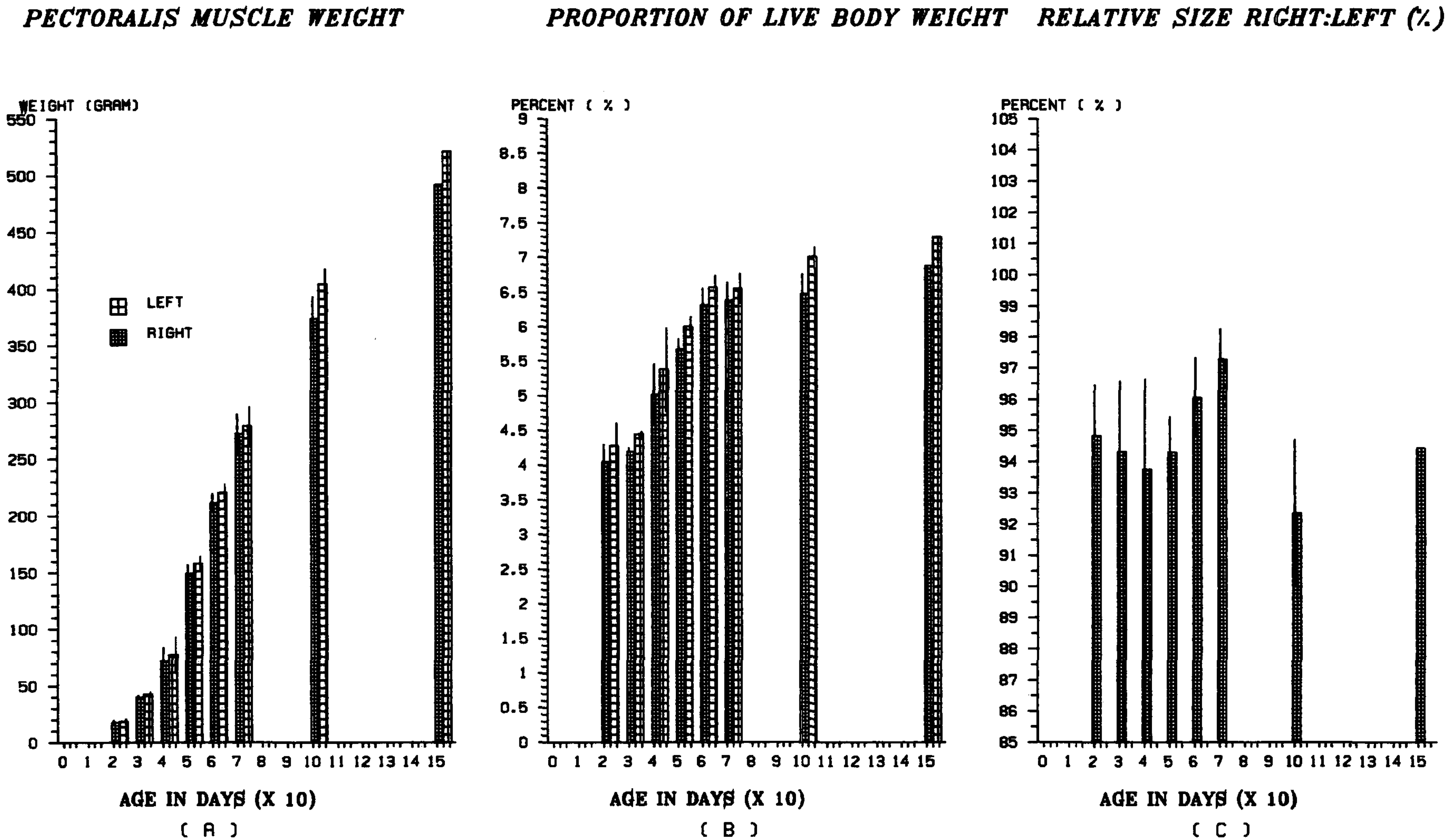
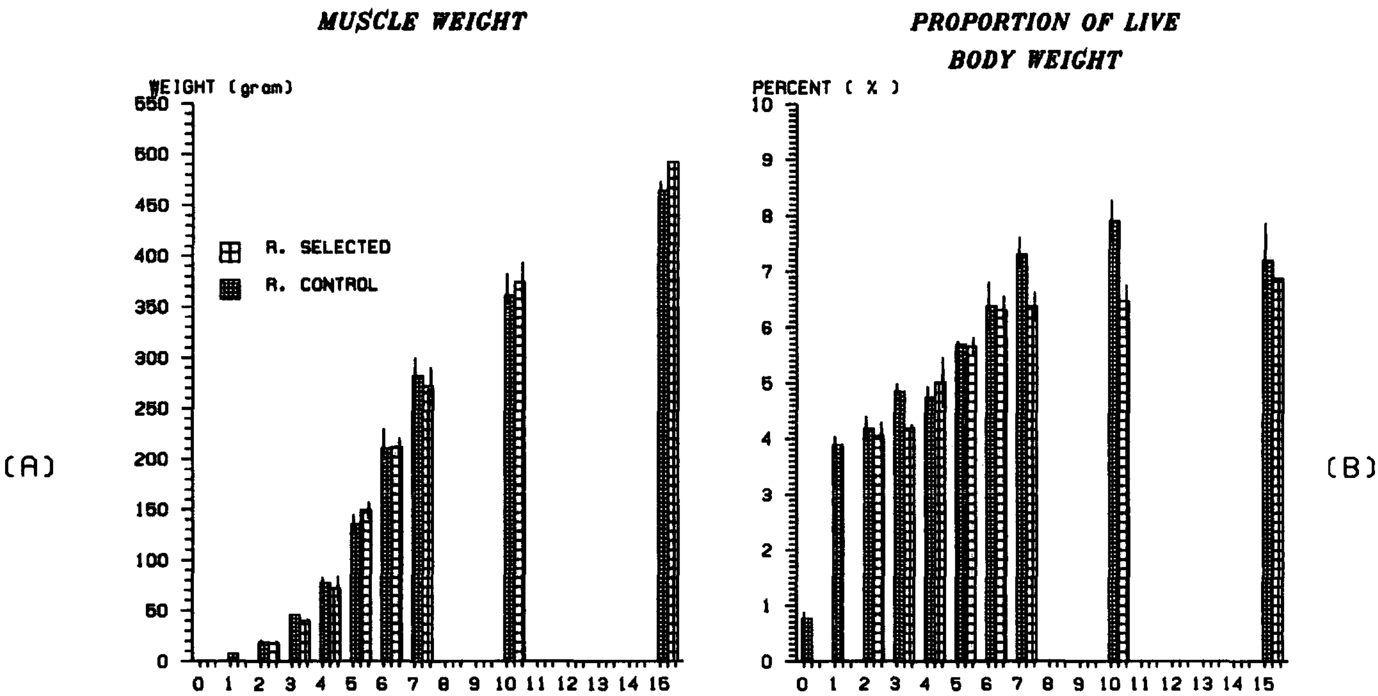


FIGURE 3.6 – PECTORALIS MUSCLE IN SELECTED CHICKENS

(OVERALL MEAN WITH STANDARD ERROR)

FIGURE 3.7 – RIGHT AND LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS

RIGHT PECTORALIS MUSCLE



LEFT PECTORALIS MUSCLE

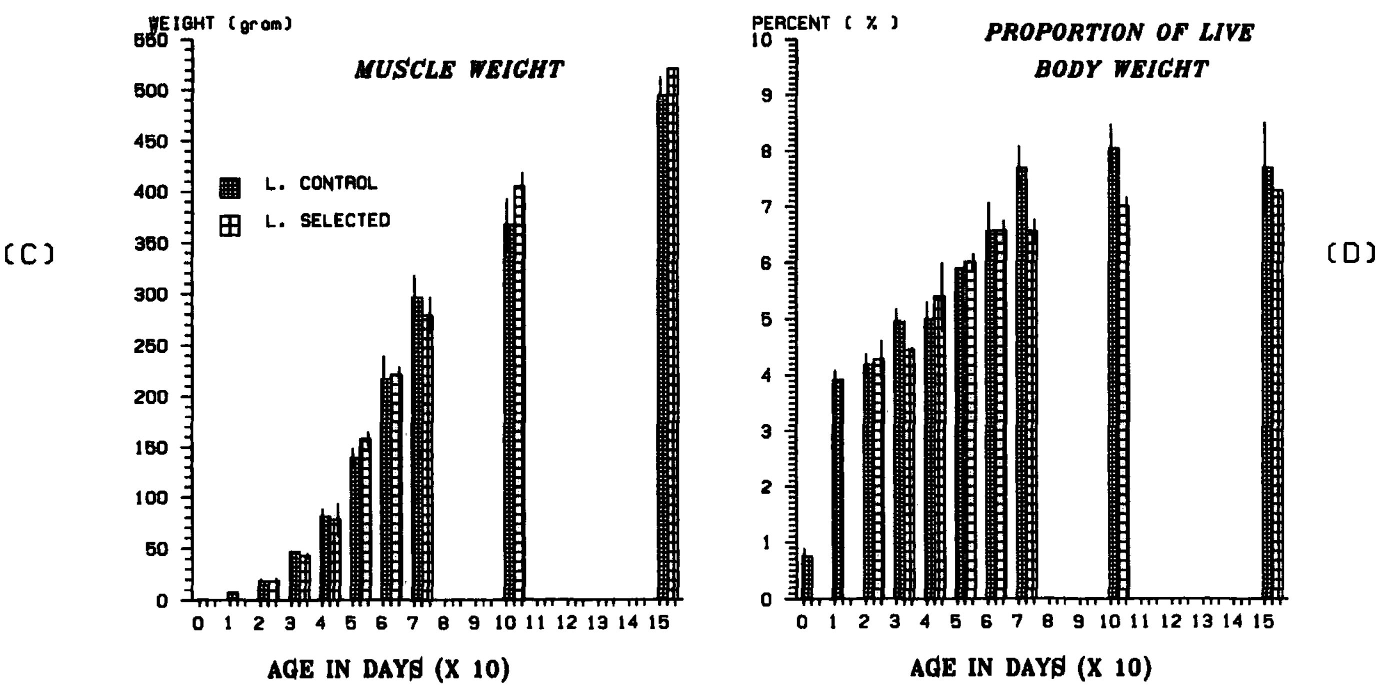


Table 3.7 — Growth Rate of Pectoralis Muscle from Hatching to 147 Days Post-Hatching in Control and Selected Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (g/10 days) ± SE	Selected Chickens Mean (g/10 days) ± SE	Significance of Difference‡
1	3/0	R	-	-	-
		L	-	-	
10	3/0	R	9.886 ± 1.029	-	-
		L	9.971 ± 1.116	-	
20	3/3	R	11.150 ± 1.970	-	-
		L	11.080 ± 1.794	-	-
30	3/2	R	27.320 ± 1.697	23.260 ± 1.760	N.S.
		L	28.173 ± 2.027	24.570 ± 1.200	N.S.
40	3/3	R	31.247 ± 5.268	31.690 ± 12.625	N.S.
		L	34.317 ± 7.098	34.903 ± 16.236	N.S.
50	3/3	R	57.617 ± 3.902	77.363 ± 10.853	N.S.
		L	58.160 ± 4.050	78.953 ± 10.654	N.S.
60	3/3	R	75.600 ± 13.770	62.510 ± 7.273	N.S.
		L	77.537 ± 16.729	62.260 ± 3.760	N.S.
70	3/3	R	71.697 ± 5.660	60.107 ± 10.064	N.S.
		L	79.837 ± 2.386	58.843 ± 9.784	N.S.
100	3/3	R	26.701 ± 1.443	34.107 ± 7.113	N.S.
		L	23.568 ± 2.313	41.823 ± 3.696	4.19*
150	3/1	R	15.504 ± 1.988	23.620	-
		L	28.018 ± 4.008	25.523	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between each side in the control chickens to its corresponding one in the selected chickens.

FIGURE 3.8 – GROWTH RATE OF PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS

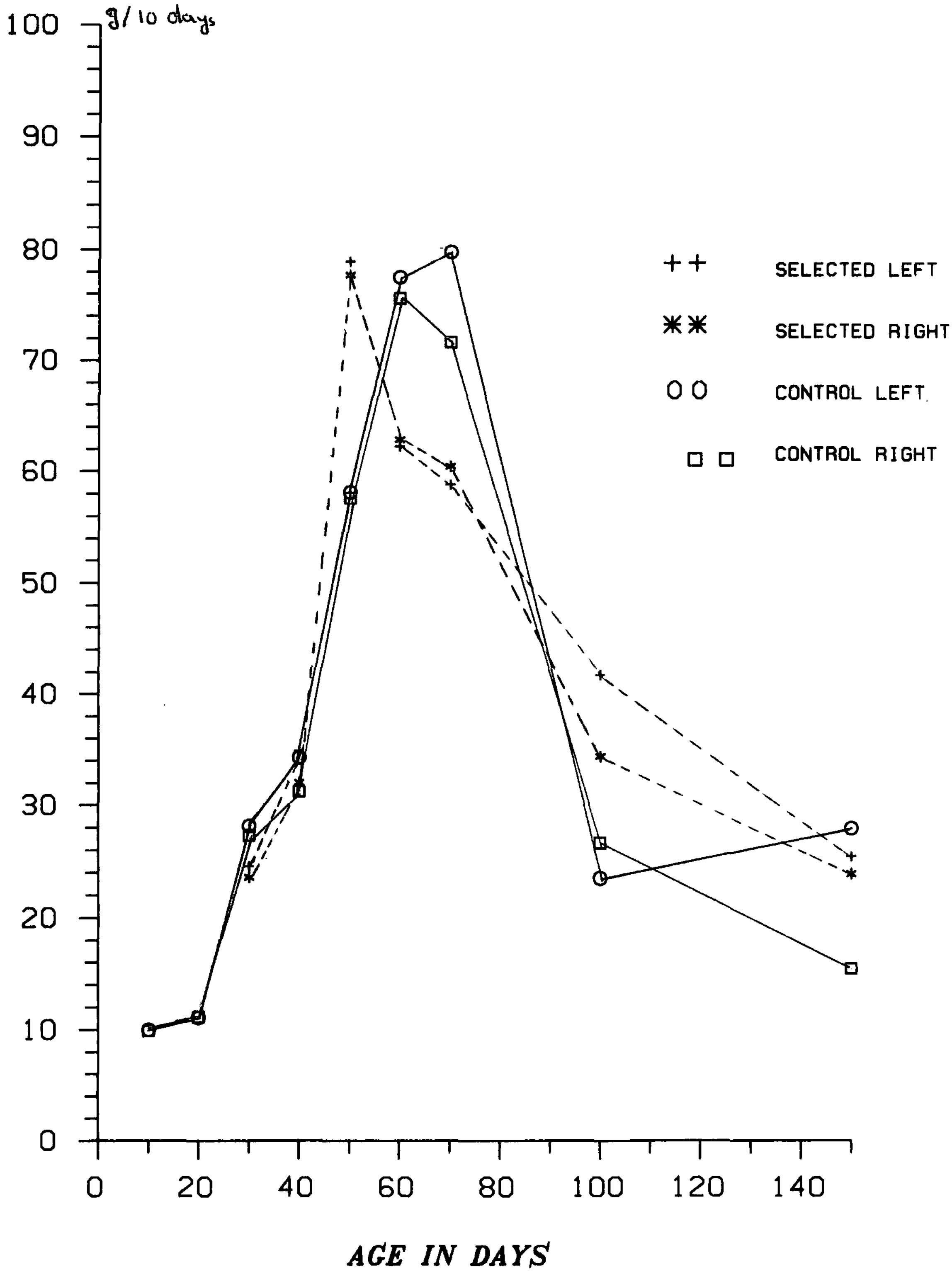


Table 3.8 — Proportion of Pectoralis Muscle as a Percentage of Live Body Weight from Hatching to 147 Days Post-Hatching in Control and Selected Broiler Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (%) ± SE	Selected Chickens Mean (%) ± SE	Significance of Difference‡
1	3/0	R	0.758 ± 0.124	–	-
		L	0.755 ± 0.136	–	
10	3/0	R	3.889 ± 0.150	–	-
		L	3.914 ± 0.176	–	
20	3/3	R	4.178 ± 0.224	4.044 ± 0.256	N.S.
		L	4.179 ± 0.179	4.276 ± 0.342	N.S.
30	3/2	R	4.850 ± 0.143	4.192 ± 0.061	4.321*
		L	4.948 ± 0.221	4.446 ± 0.042	N.S.
40	3/3	R	4.741 ± 0.206	5.018 ± 0.444	N.S.
		L	4.983 ± 0.317	5.382 ± 0.607	N.S.
50	3/3	R	5.691 ± 0.064	5.664 ± 0.163	N.S.
		L	5.884 ± 0.013	6.006 ± 0.147	N.S.
60	3/3	R	6.377 ± 0.437	6.313 ± 0.251	N.S.
		L	6.564 ± 0.506	6.568 ± 1.179	N.S.
70	3/3	R	7.304 ± 0.306	6.378 ± 0.267	2.284*
		L	7.681 ± 0.407	6.552 ± 0.216	N.S.
100	3/3	R	7.912 ± 0.391	6.473 ± 0.294	2.94*
		L	8.042 ± 0.442	7.003 ± 0.157	N.S.
150	3/1	R	7.215 ± 0.665	6.884	-
		L	7.694 ± 0.830	7.290	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the t-test between each side in the control chickens to its corresponding one in the selected chickens.

selected chickens. The result showed that control and selected chickens had similar growth rate without any significant differences between each side in control to its corresponding one in selected chickens, except at age 100 days when the growth rate of the left pectoralis muscle in selected chickens was marginally significantly ($p < 0.05$) higher than of the left pectoralis muscle in control chickens. However selected chickens reached their maximum growth rate at age 50 days, whereas the control chickens did so at 60 days of age.

3.3.3 Proportional Contribution of Pectoralis M. Weight to LBW

The proportions formed by the right and left pectoralis muscle weights of LBW were calculated and presented in table 3.8 for control and selected chickens, and data are plotted in figures 3.5B and 3.6B. There were no significant differences between the right and the left pectoralis in the proportion they contributed to live body weight in either control or selected chickens. A comparison between control and selected chickens was made and data are plotted in figures 3.7B and 3.7D. These figures show that the right pectoralis muscle of older selected chickens was significantly ($p < 0.05$) lower as a proportion of live body weight than that of the controls.

3.3.4 Degree of Asymmetry

The degree of asymmetry in the pectoralis muscle mass was expressed as the relative weight of the right to the left pectoralis muscle, expressed as a percentage. i.e. right/left pectoralis wet weight. Data are plotted in figure 3.9 and presented in table 3.8 for the control and selected chickens. Student's t-test was carried out to compare the degree of asymmetry between the control and selected birds. The result revealed that the degree of asymmetry was significantly different at 20

Table 3.9 — Degree of Asymmetry of the Pectoralis Muscle R/L as a Percentage from Hatching to 147 Days Post-hatching in Control and Selected Broiler Chickens

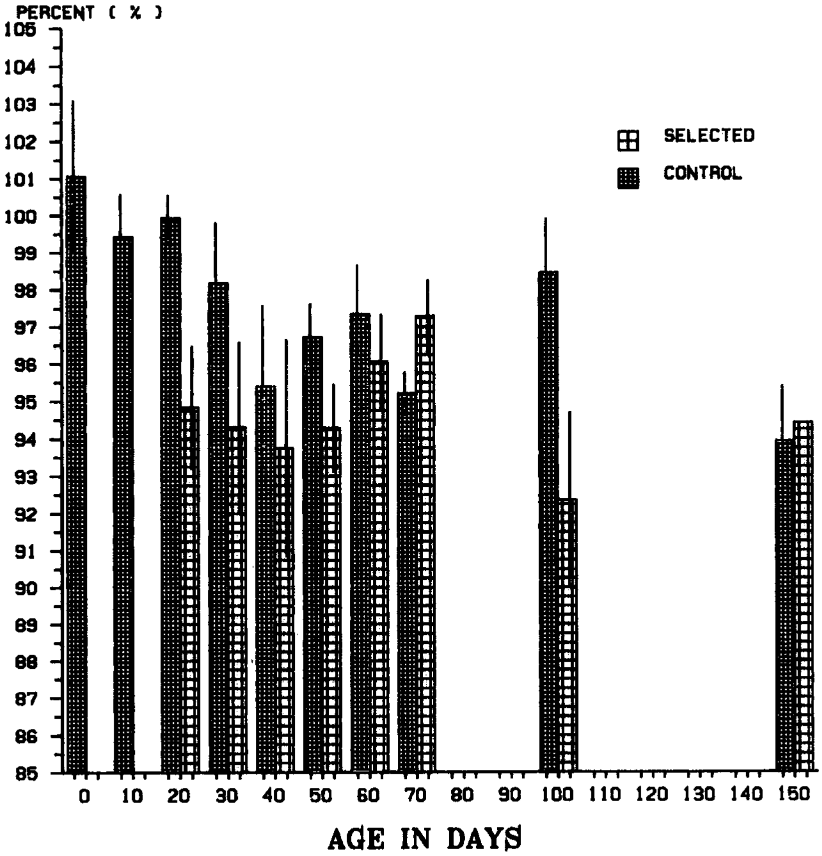
(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Control Chickens Mean (%) ± SE	Selected Chickens Mean (%) ± SE	Significance of Difference‡
1	3/0	101.061 ± 2.038	–	-
10	3/0	99.424 ± 1.181	–	–
20	3/3	99.924 ± 0.652	94.831 ± 1.642	2.883*
30	3/2	98.176 ± 1.648	94.314 ± 2.278	N.S.
40	3/3	95.388 ± 2.195	93.759 ± 2.907	N.S.
50	3/3	96.728 ± 0.899	94.287 ± 1.179	N.S.
60	3/3	97.353 ± 1.321	96.056 ± 1.288	N.S.
70	3/3	95.208 ± 0.577	97.285 ± 1.003	N.S.
100	3/3	98.459 ± 1.070	92.349 ± 2.368	N.S.
150	3/1	93.930 ± 1.481	94.430	–

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between the control and selected chickens.

FIGURE 3.9 – DEGREE OF ASYMMETRY OF THE PECTORALIS MUSCLE R/L AS A PERCENTAGE IN CONTROL AND SELECTED CHICKENS



days of age only ($p < 0.05$) as shown in figure 3.9. Also, the overall mean of the degree of asymmetry for the chickens aged between 20 and 150 days in both control and selected chickens was calculated from the individual bird data. These means with standard error were 96.896 $\pm$ 0.70 and 94.664 $\pm$ 0.52 for the control and selected chickens respectively. This overall mean was significantly ($p < 0.05$) higher in selected chickens than in controls. Taken together with the results of the previous section (3.3.3) this suggests that selected chickens had relatively a smaller pectoralis muscle at the right side than did controls.

3.4 Relative Growth of Pectoralis Muscle

Log-transformed regression statistics for pectoralis muscle wet weight on several variables were studied individually. The results of regression analysis of pectoralis muscle weight of control and selected chickens is given respectively in tables 3.10 and 3.11.

3.4.1 Pectoralis Muscle Vs. Live Body Weight

The allometric growth coefficient was significantly greater than one in both control and selected chickens, and there was no significant differences between the right and the left pectoralis muscle in both control and selected chickens. Also, no significant differences were found between the right of the control and the right in selected chickens, and the left in the control and the left in selected chickens. Therefore, regression lines of pectoralis muscle weight against LBW for both sides in control and selected chickens were parallel and identical.

Table 3.10 — Result of Regression Analysis of the Right and Left Pectoralis Muscle on Various Parameters in Control Broiler Chickens from 1 to 70 Days of Age

		Y-Intercept a	Growth Coeffiecent b ± SE ¶	R^2	F-test† at d.f.=14	t-test‡ at d.f.=14
Body Weight	R	− 2.5798	1.4096 ** ± 0.0850	0.9787	N.S.	N.S.
	L	− 2.6019	1.4206 ** ± 0.0837	0.9796		
Supracora-coidus Muscle	R	0.6245	0.9629 ** ± 0.0084	0.9995	N.S.	N.S.
	L	0.6434	0.9545 * ± 0.0148	0.9986		
Heart Weight	R	0.4261	1.5419 ** ± 0.1214	0.9641	N.S.	N.S.
	L	0.4277	1.5539 ** ± 0.1208	0.9650		
Keel Length	R	− 4.7298	3.4384 *** ± 0.1176	0.9930	N.S.	N.S.
	L	− 4.7670	3.4644 *** ± 0.1149	0.9934		
Keel Height	R	− 2.6822	3.2362 * ± 0.0956	0.9948	N.S.	N.S.
	L	− 2.6383	3.2178 ± 0.1026	0.9939		
Clavicle Length	R	− 4.1903	3.7452 * ± 0.2233	0.9791	N.S.	N.S.
	L	− 4.1950	3.7527 * ± 0.2042	0.9825		
Posterior X. Process Length	R	− 3.2668	3.1319 ± 0.1914	0.9781	N.S.	N.S.
	L	− 1.9138	2.3330 ± 0.4391	0.8247		
Anterior X. Process Length	R	− 2.9181	3.3529 * ± 0.1292	0.9912	N.S.	N.S.
	L	− 2.6935	3.2069 * ± 0.0820	0.9961		
Bone Keel Length	R	− 1.1647	2.0954 ± 0.6451	0.6375	N.S.	N.S.
	L	− 1.1797	2.1150 ± 0.6476	0.6400		
Dorsal Keel Width	R	− 2.7894	3.8336 *** ± 0.1143	0.9947	N.S.	N.S.
	L	− 2.8113	3.8621 *** ± 0.1137	0.9948		

¶ Number of asterisks indicate allometric coefficient significantly different from the unit at 0.05(*), 0.01(**), and 0.001(***) level.

‡ F-test to determine whether there is difference between the two regressions or not.

‡ t-test to determine whether the slopes of the two date differ or not.

Table 3.11 — Result of Regression Analysis of the Right and Left Pectoralis Muscles on Various Parameters in Selected Chickens from 20 to 70 Days of Age

		Y-Intercept a	Growth Coeffiecent b ± SE ¶	R^2	F-test† at d.f.=10	t-test‡ at d.f.=10
Body Weight	R	− 1.9940	1.2202 ** ± 0.0299	0.9976	N.S.	N.S.
	L	− 1.9315	1.2079 ** ± 0.0294	0.9976		
Supracora-	R	0.5529	1.0021 ± 0.0369	0.9946	N.S.	N.S.
coidus Muscle	L	0.5597	1.0111 ± 0.0452	0.9921		
Heart Weight	R	0.6230	1.2407 ± 0.0921	0.9784	N.S.	N.S.
	L	0.6588	1.2289 ± 0.0892	0.9793		
Keel Length	R	− 4.8185	3.4788 ± 0.2068	0.9861	N.S.	N.S.
	L	− 4.7179	3.4389 ± 0.2246	0.9832		
Keel Height	R	− 2.8004	3.3037 ± 0.1212	0.9946	N.S.	N.S.
	L	− 2.5824	3.1690 ± 0.1898	0.9859		
Clavicle Length	R	− 4.1948	3.8404 * ± 0.2612	0.9818	N.S.	N.S.
	L	− 4.3264	3.9322 ** ± 0.1925	0.9905		
Posterior X.	R	− 3.6533	3.3444 ± 0.2986	0.9678	N.S.	N.S.
Process Length	L	− 3.7755	3.4352 ± 0.3130	0.9678		
Anterior X.	R	− 2.4377	3.0278 ± 0.3788	0.9411	N.S.	N.S.
Process Length	L	− 2.5339	3.1182 ± 0.2123	0.9818		
Bone Keel	R	− 0.6211	1.7583 *** ± 0.1235	0.9806	N.S.	N.S.
Length	L	− 0.5697	1.7389 *** ± 0.1285	0.9786		
Dorsal Keel	R	− 2.0087	3.1227 ± 0.2347	0.9779	N.S.	N.S.
Width	L	− 1.9385	3.0853 ± 0.2513	0.9741		

¶ Number of asterisks indicate allometric coefficient significantly different from the unit.

at 0.05(*), 0.01(**), and 0.001(***) level.

‡ F-test to determine whether there is difference between the two regressions or not.

‡ t-test to determine whether the slopes of the two date differ or not.

3.4.2 Pectoralis Muscle Vs. Other Variables

Allometric growth coefficients of pectoralis muscle on: supracoracoideus muscle, heart weight, total keel length, keel height, clavicle length, posterior and anterior xiphisternal process length, bone keel length, and dorsal keel length were calculated and are presented in tables 3.10 and 3.11 for control and selected chickens respectively. There was no significant difference between the allometric growth coefficients for the right and left sides in control and selected chickens on all the above variables. Moreover, a comparison between corresponding sides in control and selected chickens was carried out and the result showed no significant differences in allometric growth coefficient.

3.5 Supracoracoideus Muscle

The absolute mean wet weight, proportional contribution to LBW, and relative weight of the right to left (degree of asymmetry) of supracoracoideus muscle in control and selected chickens for each age group are presented in tables 3.12, 3.13, 3.14 and 3.15 respectively.

3.5.1 Absolute Wet Weight of Supracoracoideus Muscle

Supracoracoideus muscle wet weight data are plotted in figures 3.10A and 3.11A for control and selected chickens respectively. There were neither significant differences between the right and the left wet weight of supracoracoideus muscle in selected chickens, nor in the controls.

Furthermore, Student's t-test was carried out to compare each supracoracoideus muscle for each side in control chickens with its corresponding side in selected chickens. The data were plotted in figures 3.12A and 3.12C for the right

Table 3.12 — Supracoracoideus Muscle Weight from Hatching to 147 Days Post-Hathcing in Control and Selected Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (g) ± SE	Selected Chickens Mean (g) ± SE	Significance of Difference‡
1	3/0	R	0.077 ± 0.018	–	-
		L	0.073 ± 0.018	–	
10	3/0	R	1.760 ± 0.173	–	-
		L	1.843 ± 0.205	–	
20	3/3	R	4.677 ± 0.500	4.713 ± 0.577	N.S.
		L	4.820 ± 0.615	4.850 ± 0.539	N.S.
30	3/2	R	13.067 ± 0.238	12.795 ± 0.455	N.S.
		L	13.013 ± 0.342	13.420 ± 0.500	N.S.
40	3/3	R	21.170 ± 1.522	19.167 ± 2.279	N.S.
		L	22.170 ± 1.601	19.287 ± 2.268	N.S.
50	3/3	R	36.190 ± 1.885	38.093 ± 2.280	N.S.
		L	37.010 ± 1.928	38.717 ± 2.013	N.S.
60	3/3	R	56.720 ± 2.170	56.950 ± 2.081	N.S.
		L	57.397 ± 3.157	56.477 ± 1.867	N.S.
70	3/3	R	73.210 ± 2.246	77.073 ± 2.774	N.S.
		L	70.950 ± 0.762	77.697 ± 2.093	2.850*
100	3/3	R	86.707 ± 1.075	109.033 ± 4.864	4.482*
		L	87.817 ± 0.203	108.923 ± 5.698	3.702*
150	3/1	R	134.40 ± 1.995	137.960	-
		L	134.575 ± 1.000	134.940	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the t-test between each side in the control chickens to its corresponding one in the selected chickens.

SUPRACORACOIDEUS MUSCLE WEIGHT   *PROPORTION OF LIVE BODY WEIGHT*   *RELATIVE SIZE RIGHT:LEFT (%)*

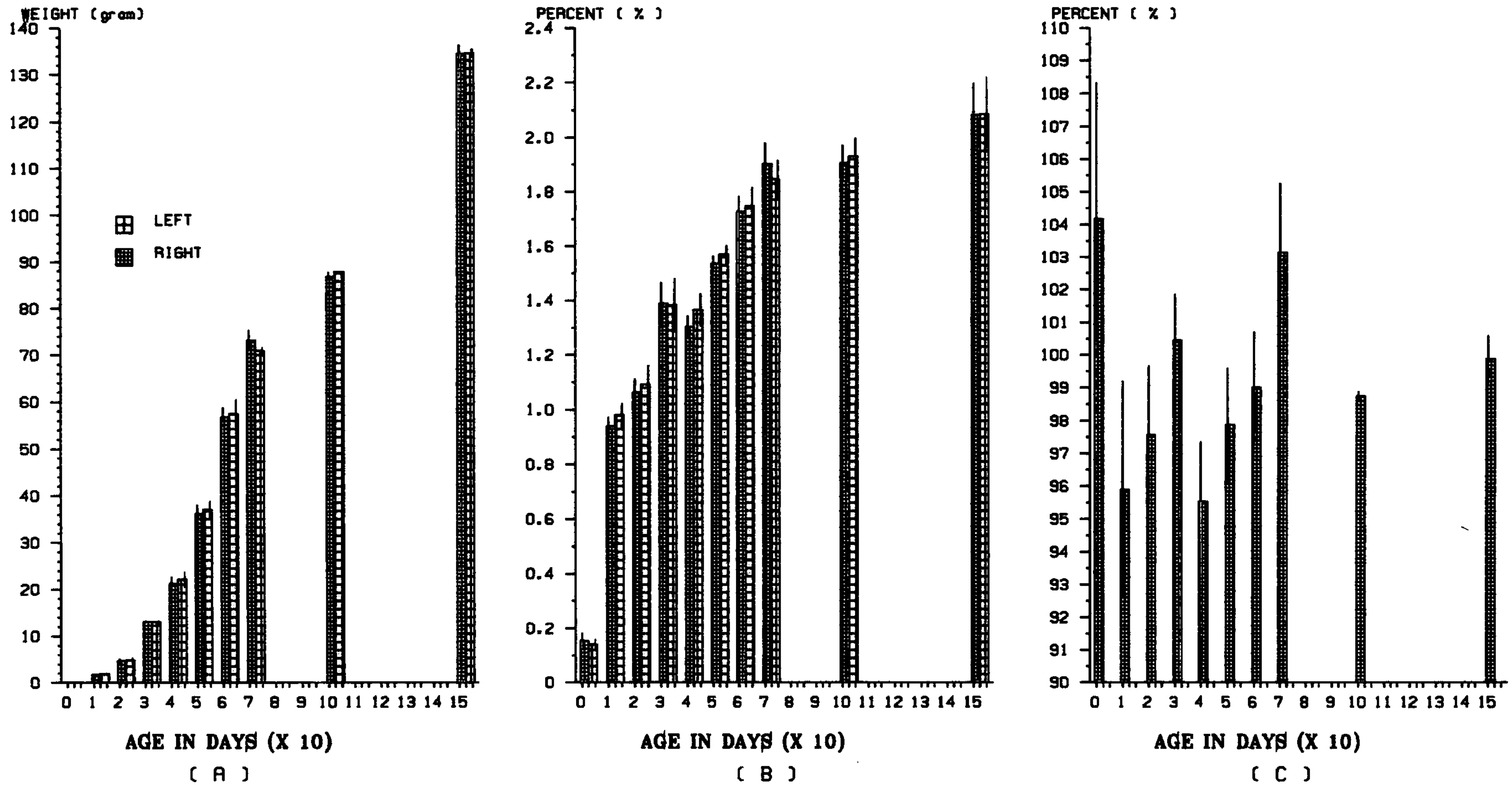


FIGURE 3.10 – SUPRACORACOIDEUS MUSCLE IN CONTROL CHICKENS
(OVERALL MEAN WITH STANDARD ERROR)

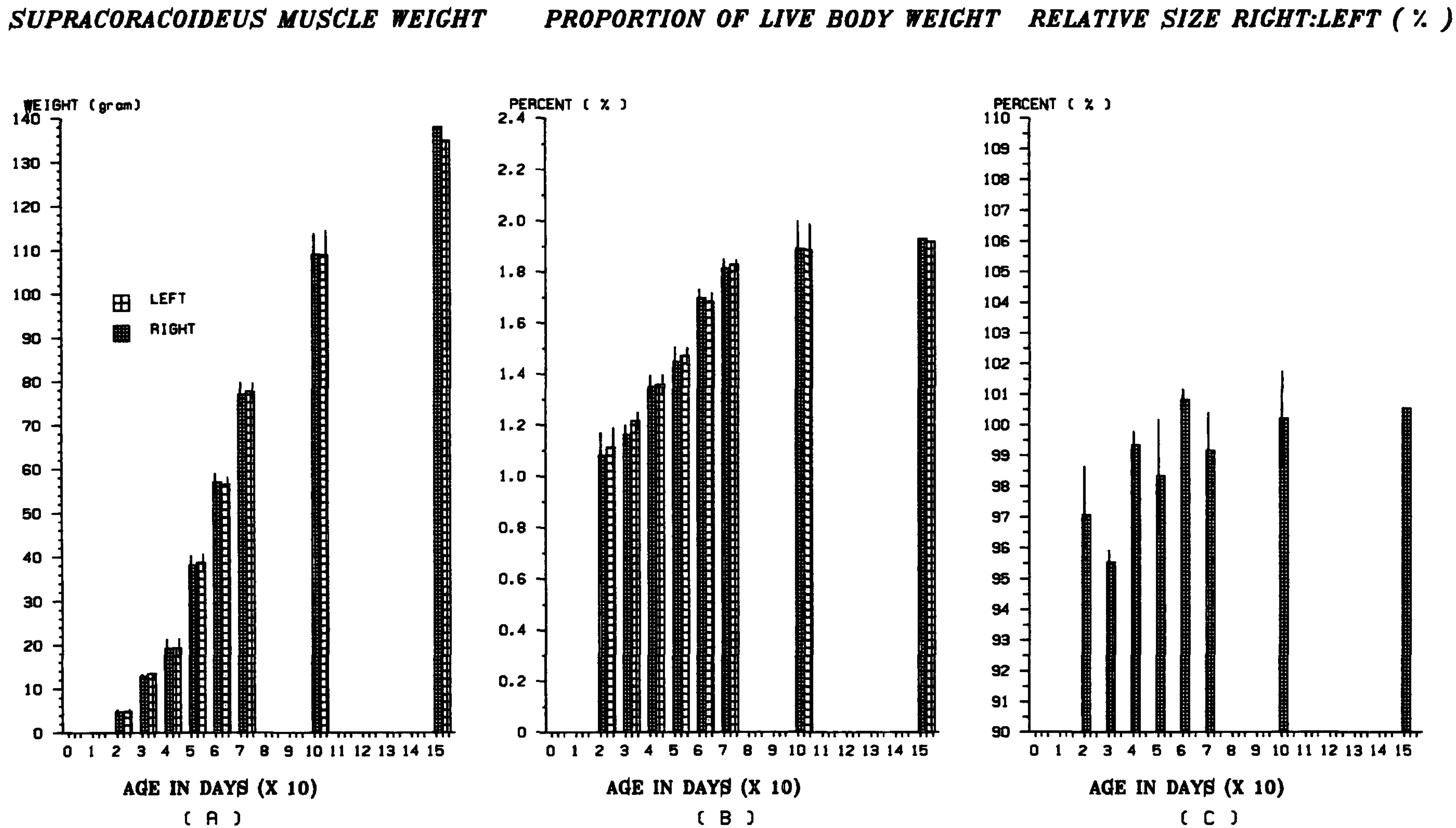
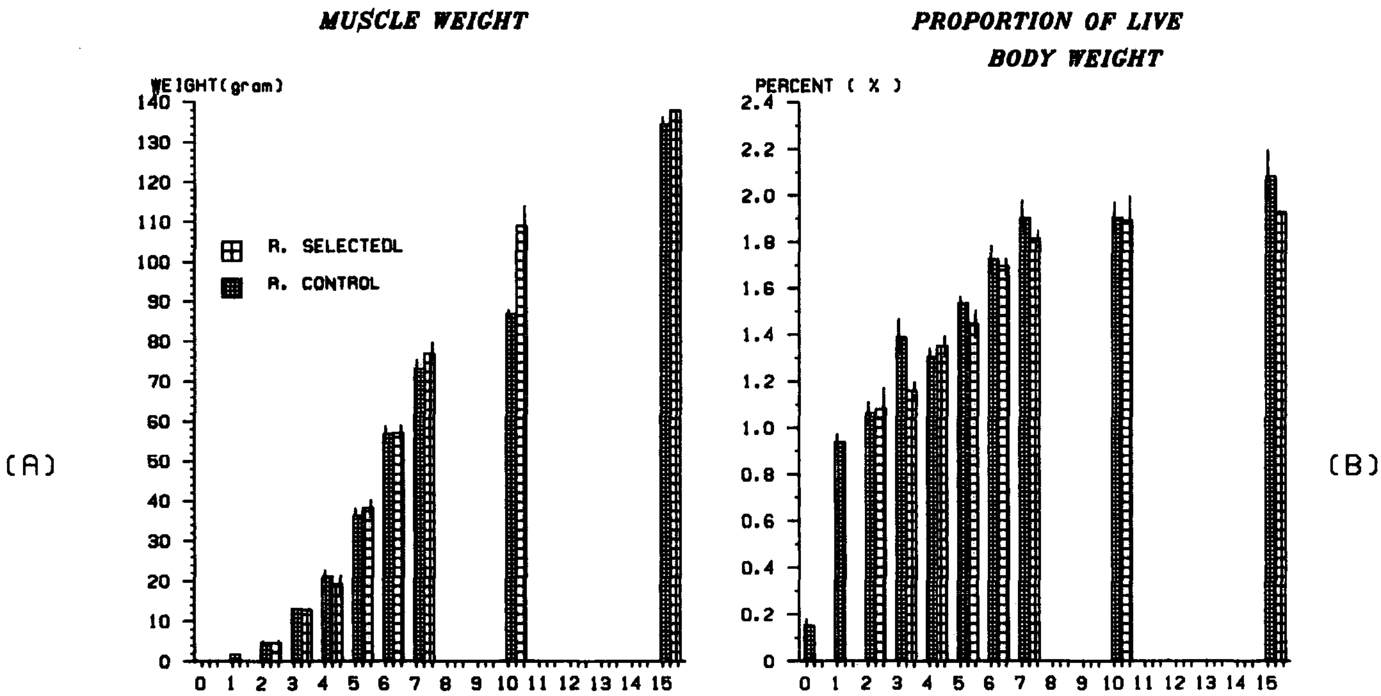


FIGURE 3.11 – SUPRACORACOIDEUS MUSCLE IN SELECTED CHICKENS

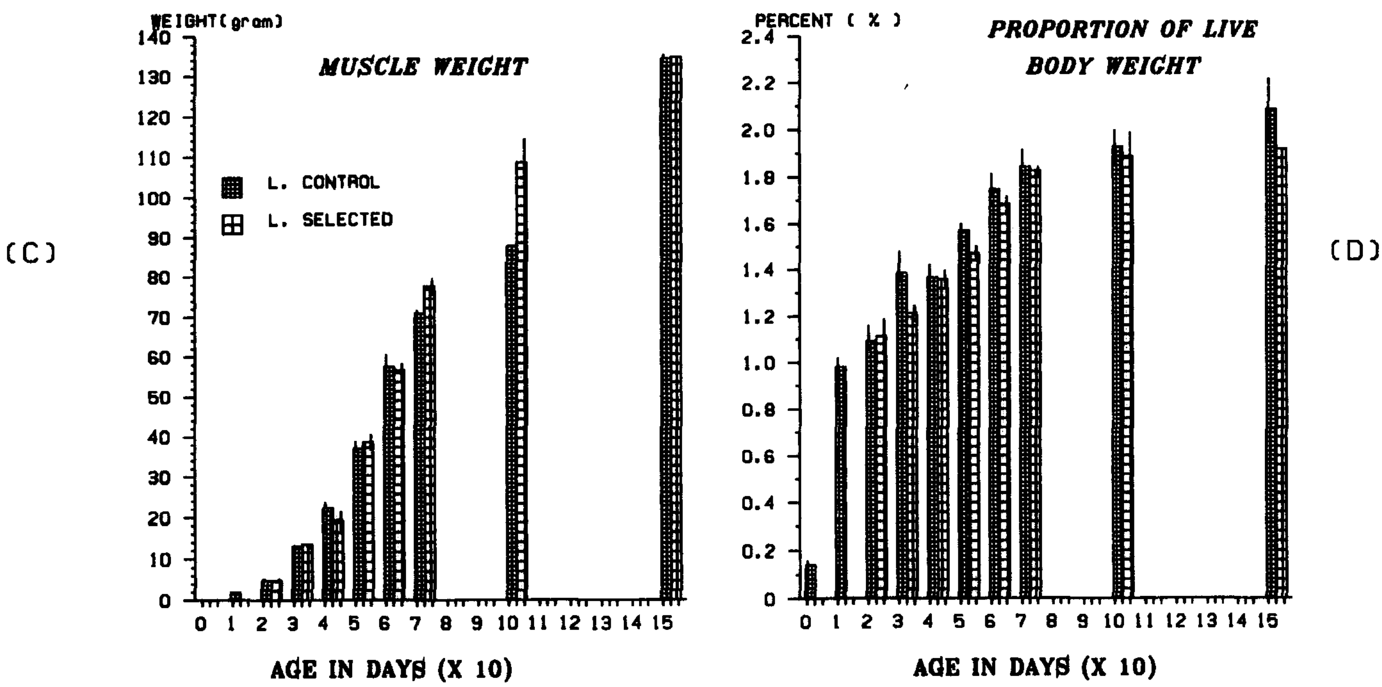
(OVERALL MEAN WITH STANDARD ERROR)

FIGURE 3.12 – RIGHT AND LEFT SUPRACORACOIDEUS MUSCLE IN CONTROL AND SELECTED CHICKENS

RIGHT SUPRACORACOIDUS MUSCLE



LEFT SUPRACORACOIDEUS MUSCLE



the left side. Selected chickens had significantly ($p < 0.05$) heavier left supracoracoideus muscle at 70 and 100 days, whereas the right supracoracoideus muscle was only significantly ($p < 0.05$) heavier at 100 days of age.

3.5.2 Proportional contribution of Supracoracoideus M. to LBW

There were no significant differences obtained in the proportion of LBW formed by the right and the left side of supracoracoideus either in control or in selected chickens (see figure 3.10B and 3.11B). Also no significant differences were revealed between each side of the control chickens and the corresponding side in the selected chickens as shown in figures 3.12B and 3.12D.

3.5.3 Growth Rate of Supracoracoideus Muscle

Data of the supracoracoideus muscle growth rate are plotted in figure 3.13. The right and the left supracoracoideus muscles grew with no significant differences in rate either in control or in selected chickens.

3.5.4 Degree of Asymmetry

Data of the degree of asymmetry are plotted in figure 3.14. Student's *t*- test revealed no significant difference in the degree of asymmetry of supracoracoideus between the two groups of chickens. Moreover the overall mean was 99.024% $\pm$ 0.796 and 98.876% $\pm$ 0.645 in control and selected chickens respectively. These overall means are not significantly different, and the muscles are less asymmetrical than the pectoralis muscle.

Table 3.13 — Proportion of Supracoracoideus Muscle as a Percentage of Live Body Weight from Hatching to 147 Days Post-Hatching in Control and Selected Broiler Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (%) ± SE	Selected Chickens Mean (%) ± SE	Significance of Difference‡
1	3/0	R	0.152 ± 0.030	–	-
		L	0.140 ± 0.020	–	
10	3/0	R	0.939 ± 0.035	–	-
		L	0.980 ± 0.044	–	
20	3/3	R	1.063 ± 0.050	1.081 ± 0.090	N.S.
		L	1.091 ± 0.071	1.112 ± 0.078	N.S.
30	3/2	R	1.388 ± 0.079	1.161 ± 0.038	N.S.
		L	1.384 ± 0.098	1.215 ± 0.035	N.S.
40	3/3	R	1.304 ± 0.039	1.350 ± 0.045	N.S.
		L	1.366 ± 0.058	1.358 ± 0.040	N.S.
50	3/3	R	1.535 ± 0.030	1.446 ± 0.060	N.S.
		L	1.570 ± 0.033	1.470 ± 0.033	N.S.
60	3/3	R	1.727 ± 0.058	1.697 ± 0.035	N.S.
		L	1.746 ± 0.070	1.683 ± 0.035	N.S.
70	3/3	R	1.903 ± 0.078	1.812 ± 0.039	N.S.
		L	1.845 ± 0.071	1.827 ± 0.020	N.S.
100	3/3	R	1.905 ± 0.068	1.891 ± 0.108	N.S.
		L	1.929 ± 0.070	1.886 ± 0.103	N.S.
150	3/1	R	2.082 ± 0.117	1.929	-
		L	2.086 ± 0.133	1.919	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between each side in the control chickens to its corresponding one in the selected chickens.

Table 3.14 — Growth Rate of Supracoracoideus Muscle from Hatching to 150 Days Post-Hatching in Control and Selected Chickens

(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Side	Control Chickens Mean (g/10 days) ± SE	Selected Chickens Mean (g/10 days) ± SE	Significance of Difference‡
1	3/0	R	-	-	-
		L	-	-	
10	3/0	R	2.404 ± 0.234	-	-
		L	2.529 ± 0.276	-	
20	3/3	R	2.917 ± 0.488	-	-
		L	2.977 ± 0.549	-	-
30	3/2	R	8.403 ± 0.742	8.075 ± 1.455	N.S.
		L	8.290 ± 1.038	8.640 ± 1.460	N.S.
40	3/3	R	8.103 ± 1.654	6.373 ± 2.255	N.S.
		L	9.167 ± 1.914	5.867 ± 2.252	N.S.
50	3/3	R	15.020 ± 0.466	18.927 ± 2.414	N.S.
		L	14.843 ± 0.835	17.760 ± 0.540	N.S.
60	3/3	R	20.530 ± 1.777	18.857 ± 1.313	N.S.
		L	20.387 ± 2.991	17.760 ± 0.540	N.S.
70	3/3	R	16.490 ± 0.150	20.123 ± 1.728	N.S.
		L	13.553 ± 2.398	21.220 ± 0.863	3.008*
100	3/3	R	4.499 ± 0.596	10.653 ± 2.120	2.794*
		L	5.622 ± 0.339	10.409 ± 1.889	N.S.
150	3/1	R	9.363 ± 0.611	5.786	-
		L	9.156 ± 0.376	5.660	-

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between each side in the control chickens to its corresponding one in the selected chickens.

FIGURE 3.13 – GROWTH RATE OF SUPRACORACOIDEUS MUSCLE IN CONTROL AND SELECTED CHICKENS

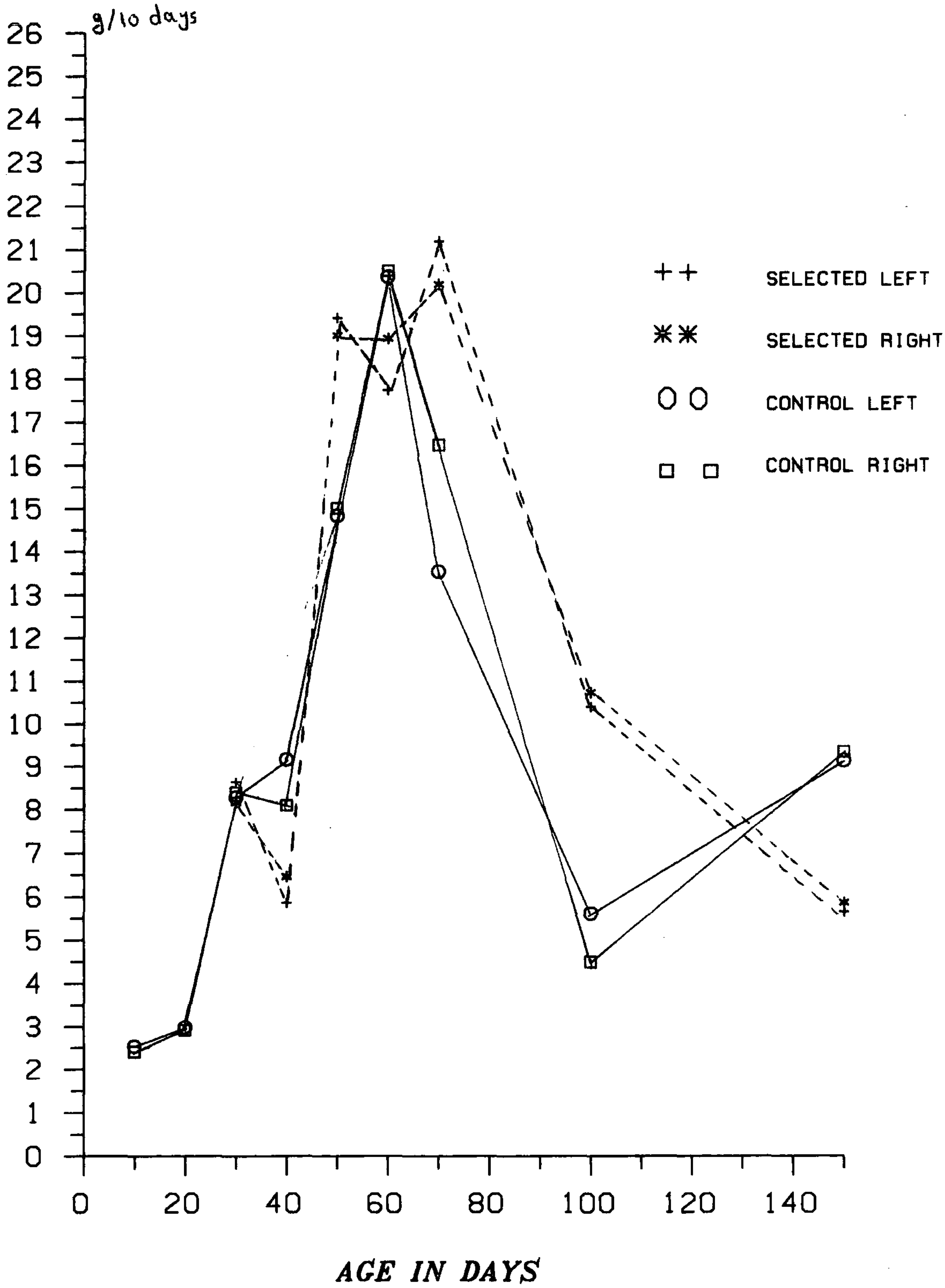


Table 3.15 — Degree of Asymmetry of the Supracoracoideus Muscle R/L as a Percentage from Hatching to 147 Days Post-hatching in Control and Selected Broiler Chickens

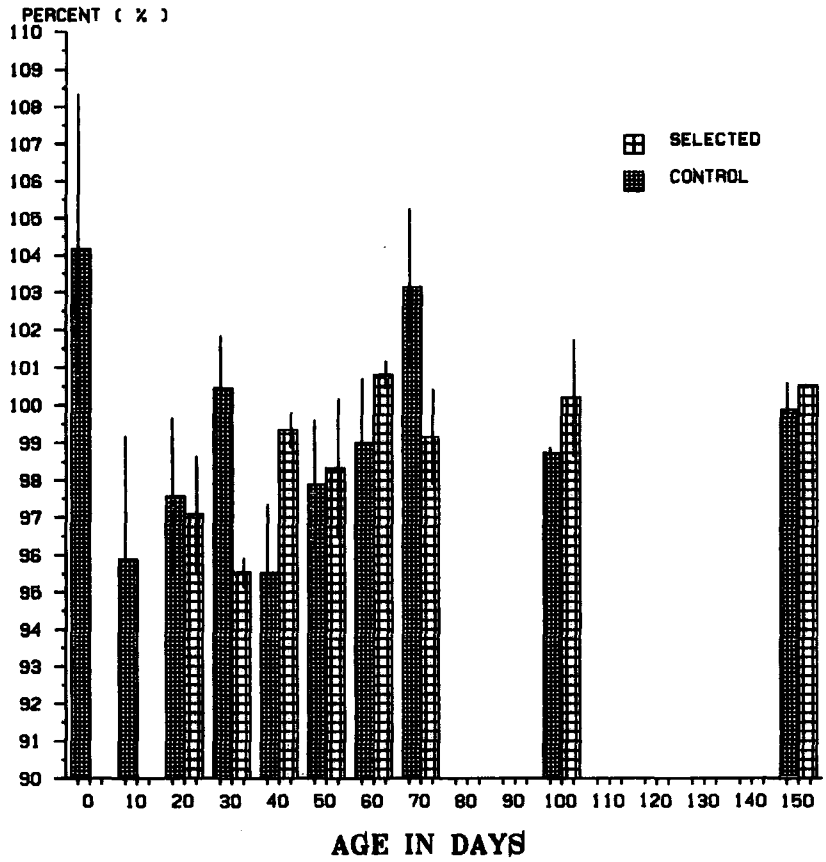
(Mean ± SE given for each measurement)

Age in Days	Number of Birds C/S†	Control Chickens Mean (%) ± SE	Selected Chickens Mean (%) ± SE	Significance of Difference‡
1	3/0	104.167 ± 4.167	–	-
10	3/0	95.894 ± 3.303	–	–
20	3/3	97.565 ± 2.111	97.074 ± 1.584	N.S.
30	3/2	100.460 ± 1.403	95.537 ± 0.403	N.S.
40	3/3	95.525 ± 1.841	99.348 ± 0.458	N.S.
50	3/3	97.883 ± 1.721	98.327 ± 1.852	N.S.
60	3/3	99.005 ± 1.718	100.815 ± 0.361	N.S.
70	3/3	103.140 ± 2.134	99.158 ± 1.258	N.S.
100	3/3	98.740 ± 0.154	100.207 ± 1.547	N.S.
150	3/1	99.872 ± 0.740	100.539	–

†C/S: Number of control and selected chickens respectively.

‡Degree of significance at (n1+n2−2) d.f. of the *t*-test between the control and selected chickens.

FIGURE 3.14 - DEGREE OF ASYMMETRY OF THE SUPRACORACOIDEUS MUSCLE R/L AS A PERCENTAGE IN CONTROL AND SELECTED CHICKENS



3.6 Relative Growth of Supracoracoideus Muscle Weight

Supracoracoideus muscle wet weight was transformed to logarithms before regression analysis against live body weight. The results of regression analysis of supracoracoideus muscle in control and selected chickens is given in table 3.16. Analysis of variance was carried out to find out whether the allometric growth coefficients of supracoracoideus muscle in control and selected chickens are different or not.

Table 3.16 — Result of Regression Analysis of Supracoracoideus Muscle Weight on Body Weight in Control and Selected Chickens Against Age

		Y-Intercept a	Growth Coeffiecent b ± SE ¶	R^2	F-test† at d.f.=14	t-test‡ at d.f.=14
Control	R	− 3.3225	1.4620 *** ± 0.0923	0.9767	N.S.	N.S.
	L	− 3.3785	1.4810 *** ± 0.1040	0.9713		
Selected	R	− 2.5300	1.2140 *** ± 0.0325	0.9971	N.S.	N.S.
	L	− 2.4479	1.1897 *** ± 0.0310	0.9986		

¶ Number of asterisks indicate allometric coefficient significantly different from the unit.

at 0.05(*), 0.01(**), and 0.001(***) level.

‡ F-test to determine whether there is difference between the two regressions or not.

‡ t-test to determine whether the slopes of the two date differ or not.

3.6.1 Supracoracoideus Muscle Vs. Live Body Weight

Allometric growth coefficients of supracoracoideus muscle in control and selected chickens are given in table 3.16. These were significantly greater than one for both control and selected chickens. However, there was no significant difference between the right and the left allometric growth coefficient of supracoracoideus muscle in either control or selected chickens. But, control chickens had a significantly higher allometric growth coefficient than selected chickens in both the right and the left supracoracoideus muscles ($t = 2.230$, $p < 0.05$ and 2.346, $p < 0.05$ respectively).

The conclusion for supracoracoideus muscle is that this muscle has an absolute wet weight, growth rate, percentage to live weight, and percentage of the right to the left side, all of which are very similar on the two sides of supracoracoideus muscle in control and selected chickens. Therefore the differences in the breast shape of asymmetrical chickens can not be due to the supracoracoideus, but might be due to the pectoralis muscle mass since it forms the major mass of the breast muscles. In addition to that, the left pectoralis muscle in selected chickens was heavier than the right one.

Therefore, a decision was made to continue research on pectoralis muscle by using histochemical methods to study the structure of the right and the left pectoralis muscle in selected chickens at different ages, with other chickens as control. Extensor digitorum longus (EDL) muscle from the right leg was used in histochemistry as a control to demonstrate fibre types, as shown in figure 4.2, plate 4.2. The results are described in chapter IV.

3.7 Heart

Heart growth, coupled with body size, appears to be a reliable index of heart function since blood volume is directly related to body mass (Burton, 1972). Therefore, heart growth was studied to see whether there was any difference between

Table 3.17 — Heart Weight, Growth Rate, and Proportion of Live Body Weight in Control and Selected Chickens

(Mean ± SE given for each measurement)

Age(Days)		1	10	20	30	40	50	60	70	100	150
Number of Birds N/A		3/3	3/3	3/3	3/2	3/3	3/3	3/3	3/3	3/3	2/1
Heart Weight (g)	C	0.427	1.137	3.027	6.687	9.587	14.730	17.277	19.593	24.263	31.350
		0.045	0.050	0.093	0.583	0.647	0.569	0.1560	0.750	3.195	4.530
	S	–	–	2.870	7.365	9.687	15.563	19.150	21.800	28.490	34.400
		–	–	0.121	0.965	0.858	0.173	1.902	0.500	0.875	–
Growth Rate (g/10 days)	C	–	0.710	1.890	3.660	2.900	5.143	2.547	2.317	1.557	1.379
		–	0.006	0.050	0.638	1.025	0.375	0.417	0.595	0.961	0.199
	S	–	–	–	4.493	3.155	5.877	3.587	2.653	2.228	1.182
		–	–	–	0.508	0.965	0.688	1.362	0.546	0.402	–
Proportion of Live Body Weight (%)	C	1.708	0.611	0.696	0.705	0.593	0.626	0.527	0.508	0.532	0.491
		0.593	0.029	0.038	0.041	0.041	0.021	0.017	0.003	0.070	0.105
	S	–	–	0.663	0.766	0.691	0.594	0.569	0.512	0.503	0.481
		–	–	0.021	0.059	0.068	0.032	0.016	0.013	0.014	–

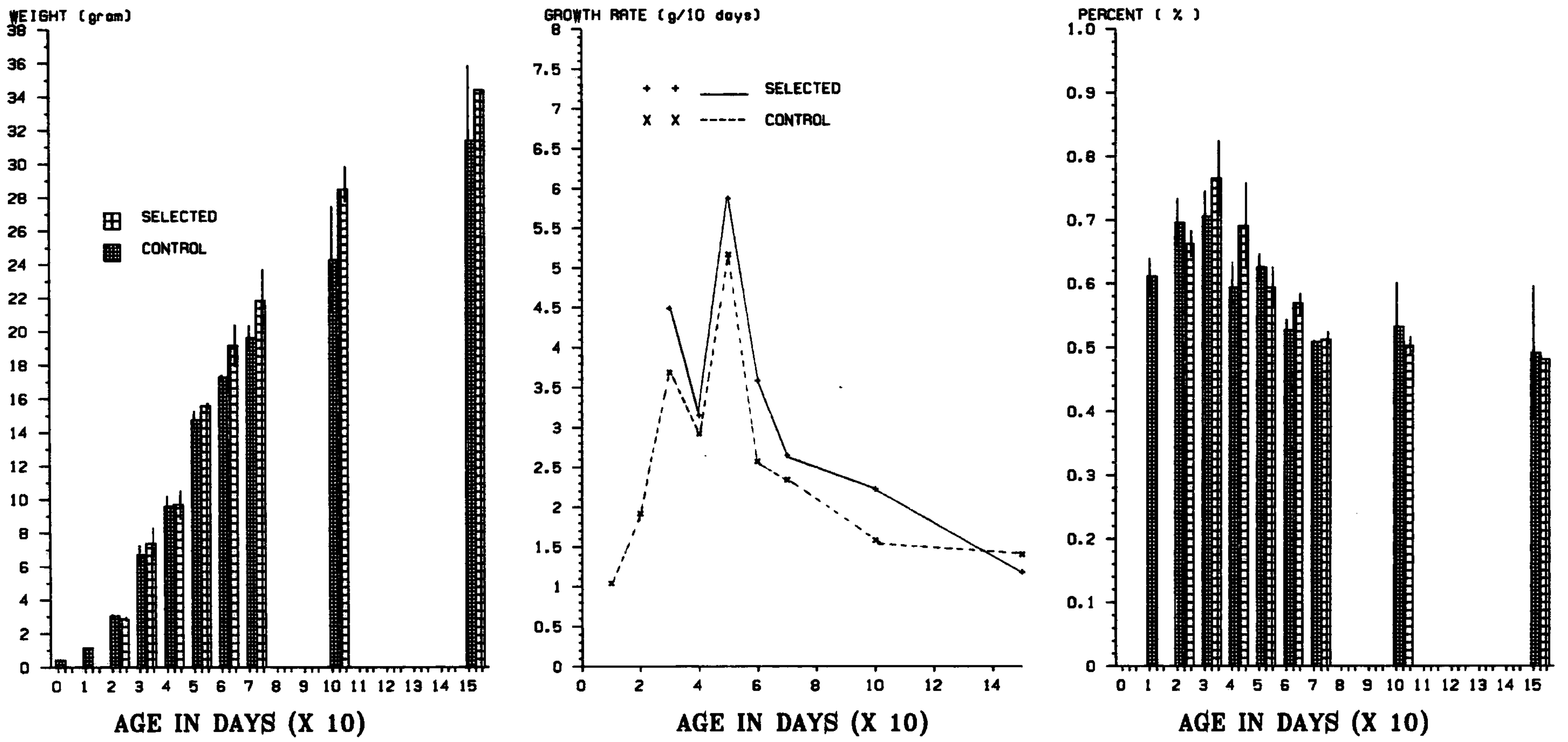
C: Control S: Selected

control and selected birds. The following measurements were taken: absolute wet weight, growth rate, and proportional contribution to LBW, of the heart. Data are presented in table 3.17 and are plotted in figure 3.15. Student's t-test revealed no significant differences for all these measurements between the two groups of chickens.

3.8 Relative Growth of Heart Weight

The relationship of heart mass to live body mass is considered frequently in the study of growth since blood volume is directly related to body mass. Therefore,

HEART WEIGHT | *HEART GROWTH RATE* | *PROPORTION OF LIVE BODY WEIGHT (%)*



(A) (B) (C)

FIGURE 3.15 – HEART IN CONTROL AND SELECTED CHICKENS

heart weights in control and selected chickens were studied as a function of the body weight.

3.8.1 Heart Weight Vs. Live Body Weight

Since heart weight is directly related to body weight as mentioned above, the allometric growth coefficient of heart weight on live body weight was calculated and data are presented in tables 3.18 for control and selected chickens. Here, the difference in allometric growth coefficient of heart weight between control and selected chickens was not significant, therefore the two slopes are identical.

Table 3.18 — Result of Regression Analysis of the Heart Weight on Body Weight in Control and selected Chickens Against Age

	Y-Intercept a	Growth Coefficient b ± SE	R^2	*F*-test	*t*-test
Control	– 1.9358	0.9091 * ± 0.0255	0.9953	N.S.	N.S.
Selected	– 1.7653	0.8662 * ± 0.0478	0.9874		

* Significantly different from one ($p < 0.05$)

The conclusion is that the heart was growing at a similar rate as a function of the body weight in both control and selected chickens.

3.9 Skeletal Growth and Development

The result of the above section was that the right pectoralis muscle in selected chickens was significantly lighter in weight than the right pectoralis muscle in the control chickens, but it was not significantly different from the left side in selected chickens. Therefore further investigation was carried out on the skeleton to find out whether there were any differences in bone length or weights between the right and left side within and between the control and selected chickens. Growth of the skeleton in both control and selected chickens was studied by taking the weight and length of some bones of the breast area to differentiate the growth of the skeleton between and within control and selected chickens.

The following skeletal parameters were measured: the length and weight of the total keel, keel bone, dorsal keel width, keel height, anterior and posterior xiphisternal process, clavicle, and coracoid; in control and selected chickens. Data are presented in tables 3.19 and 3.20 and tables 3.21 and 3.22 for the length and weight of the above parameters in control and selected chickens. Absolute values were compared between the right and left side within each group of chickens and between birds of the two groups of the same age using Student's *t*-test. Relative growth rates of each skeletal parameter (compared to live body weight) were also calculated by regression analysis and presented in tables 3.23 and 3.24 for both control and selected chickens respectively. Allometric growth coefficients (i.e. slopes(b) of the regression line) were compared to examine:

(i) whether values of b differed significantly between controls and selected birds,

(ii) whether either value differed significantly from unity (which would indicate that particular parameter grew faster/slower than live body weight).

Table 3.19 — Average Length of Different Bones in Control Broiler Chickens

(mean ± SE given for each measurement)

Age(days)		1	10	20	30	40	50	60	70	100	150
Number of Birds		3	3	3	3	3	3	3	3	3	2
Clavicle Bone	R	11.267	19.833	27.083	34.683	45.917	53.283	54.067	56.700	66.117	64.150
		0.917	0.549	0.622	0.484	1.009	1.545	0.812	0.351	3.175	2.300
	L	11.000	20.700	26.667	34.467	46.483	53.750	54.517	56.200	65.717	66.675
		0.675	0.350	0.760	0.217	0.617	1.721	0.242	0.580	2.300	0.625
Coracoid Bone	R	11.133	21.417	29.350	39.767	47.500	54.550	60.033	60.083	67.050	71.725
		0.517	0.384	1.147	1.482	0.425	1.951	0.765	2.671	2.908	2.825
	L	9.917	21.533	30.000	40.000	46.883	55.267	60.400	59.817	65.950	71.525
		1.070	0.371	1.303	0.722	0.145	1.073	0.409	2.657	3.103	2.575
Posterior X. Process	R	9.317	16.867	27.700	39.467	46.100	56.067	61.750	62.233	75.283	95.550
		0.434	0.280	1.627	1.419	2.137	1.686	0.709	4.100	1.343	2.250
	L	8.633	17.483	27.617	38.033	44.417	56.667	60.333	62.483	72.500	91.225
		0.766	0.252	1.789	0.847	1.317	1.848	1.566	2.876	2.540	2.925
Anterior X. Process	R	5.866	12.050	17.257	25.267	27.377	32.550	37.250	37.850	45.033	55.875
		0.145	0.351	1.377	1.482	0.264	0.202	0.482	1.175	0.677	0.725
	L	5.150	12.300	17.417	24.283	26.967	33.867	36.883	38.200	42.767	52.600
		0.645	0.176	1.278	0.786	0.291	1.801	1.169	1.554	0.809	0.250
Keel Height	R	5.000	11.767	17.100	23.467	27.433	30.533	33.967	36.417	41.150	48.425
		0.346	0.561	1.054	0.394	1.442	1.677	0.518	0.335	0.647	0.325
	L	4.933	11.383	16.983	23.467	26.800	31.350	33.733	36.550	43.050	49.500
		0.366	0.593	1.265	0.432	1.125	1.381	0.933	0.125	1.978	0.500
Dorsal Keel Width		4.283	8.533	11.900	13.567	17.233	19.783	22.250	23.217	27.000	29.200
		0.361	0.388	0.202	0.415	0.117	0.838	1.021	1.159	2.564	0.453
Total Keel Length		19.017	38.400	53.400	72.617	88.000	104.633	112.067	118.433	142.955	157.895
		1.070	0.527	1.872	3.011	2.614	1.854	1.103	3.065	6.394	7.805
Keel Bone Length (only)		9.550	14.283	12.270	18.933	26.920	35.000	42.017	47.283	75.850	143.000
		0.679	0.892	1.345	1.542	1.669	1.839	2.566	4.822	3.603	5.996

This table derived from the raw data in appendix B.

Table 3.20 — Average Length of Different Bones in Selected Broiler Chickens

(mean ± SE given for each measurement)

Age(days)		1	10	20	30	40	50	60	70	100	150
Number of Birds		-	-	3	2	3	3	3	3	2	1
Clavicle Bone	R	–	–	26.283	33.650	36.733	43.483	48.850	55.717	58.233	56.300
		–	–	0.213	0.360	0.792	0.814	1.334	0.641	1.397	–
	L	–	–	26.300	33.750	36.867	44.383	50.783	55.300	58.883	55.750
		–	–	0.682	0.060	0.843	0.873	0.970	0.580	1.132	–
Coracoid Bone	R	–	–	33.450	39.650	43.967	52.040	61.150	67.183	72.500	69.350
		–	–	1.297	2.000	1.015	1.210	0.458	1.239	0.437	–
	L	–	–	30.983	40.600	44.183	51.850	60.000	66.967	71.750	68.400
		–	–	2.435	1.850	1.596	0.939	0.895	1.438	0.275	–
Posterior X. Process	R	–	–	31.267	36.675	42.150	51.450	63.517	68.583	85.633	88.250
		–	–	0.371	0.275	1.879	1.255	1.866	1.516	1.642	–
	L	–	–	31.433	36.183	42.467	50.933	62.850	66.917	82.333	83.450
		–	–	1.568	0.750	1.993	2.002	2.139	0.780	0.798	–
Anterior X. Process	R	–	–	18.517	21.375	23.417	31.100	37.750	43.500	53.033	50.750
		–	–	0.593	0.825	1.822	1.375	1.665	0.957	1.478	–
	L	–	–	17.433	21.600	24.917	31.217	37.000	41.517	51.900	50.200
		–	–	1.129	0.250	1.517	1.227	0.925	0.842	0.791	–
Keel Height	R	–	–	17.100	21.450	25.467	30.783	35.900	39.423	41.433	47.750
		–	–	1.098	0.400	0.361	1.063	0.929	0.590	2.199	–
	L	–	–	17.167	21.375	26.183	31.617	35.930	40.093	43.683	48.450
		–	–	1.301	0.475	0.536	1.172	1.159	0.787	1.543	–
Dorsal Keel Width		–	–	11.633	14.525	15.983	21.483	23.917	27.967	26.833	29.800
		–	–	1.391	0.225	0.497	0.581	0.492	1.488	1.013	–
Total Keel Length		–	–	57.667	70.075	77.567	102.783	113.783	123.717	146.183	155.000
		–	–	3.611	0.425	0.510	0.209	1.284	2.029	4.502	–
Keel Bone Length (only)		–	–	11.700	19.600	25.533	34.500	44.483	61.120	75.383	139.350
		–	–	0.260	1.400	2.199	1.979	0.657	1.270	2.396	–

This table derived from the raw data in appendix B.

Table 3.21 — Average Weight of Different Bones in Control Broiler Chickens

(mean ± SE given for each measurement)

Age(days)		1	10	20	30	40	50	60	70	100	150
Number of Birds		3	3	3	3	3	3	3	3	3	2
Coracoid Bone	R	0.033	0.277	0.717	1.780	2.697	3.797	5.040	5.653	7.467	8.580
		0.009	0.018	0.080	0.119	0.071	0.568	0.189	1.213	1.610	0.560
	L	0.037	0.292	0.727	1.773	2.655	4.043	5.273	5.257	7.420	8.500
		0.009	0.019	0.088	0.118	0.015	0.578	0.350	0.848	1.443	0.800
Anterior and Posterior X. Process	R	0.012	0.067	0.173	0.487	0.580	1.017	1.360	1.463	2.023	2.790
		0.004	0.018	0.022	0.077	0.026	0.122	0.104	0.128	0.204	0.390
	L	0.012	0.057	0.160	0.430	0.603	0.917	1.473	1.393	1.867	2.745
		0.004	0.012	0.017	0.078	0.042	0.114	0.130	0.215	0.171	0.085
Clavicle Bone		0.013	0.085	0.270	0.667	0.820	1.337	1.850	1.803	3.173	3.045
		0.003	0.013	0.015	0.035	0.061	0.254	0.123	0.250	0.175	0.355
Total Keel (with cartilage)		0.207	1.173	3.390	6.807	10.677	16.453	22.340	22.130	26.233	25.575
		0.054	0.117	0.282	0.456	0.683	1.885	0.812	2.910	6.092	2.895
Keel Bone Only		0.163	0.753	2.360	4.997	7.953	11.917	16.553	16.563	21.920	24.800
		0.059	0.079	0.202	0.288	0.595	1.423	0.793	2.431	5.540	2.539

This table derived from the raw data in appendix B.

3.9.1 The Sternum

The sternum has a ventrally directed bony *Keel* , which serves as an area of origin for the breast muscles in chickens. Growth and development of the keel is directly related to the degree of development of pectoralis and supracoracoideus muscles (George and Berger, 1966). Therefore, the above parameters in the sternum were studied in control and selected chickens . Data were compared between the two groups of chickens.

Table 3.22 — Average Weight of Different Bones in Selected Broiler Chickens

(mean ± SE given for each measurement)

Age(days)		1	10	20	30	40	50	60	70	100	150
Number of Birds		–	–	3	2	3	3	3	3	2	1
Coracoid Bone	R	–	–	1.107	1.640	2.177	3.663	5.540	6.613	9.967	7.710
		–	–	0.041	0.260	0.168	0.183	0.348	0.263	0.132	–
	L	–	–	0.997	1.765	2.313	3.890	5.623	6.567	9.813	8.100
		–	–	0.086	0.305	0.275	0.184	0.173	0.115	0.303	–
Anterior and	R	–	–	0.223	0.385	0.553	1.037	1.593	2.143	3.943	2.540
Posterior X.		–	–	0.017	0.065	0.052	0.081	0.213	0.167	0.260	–
Process	L	–	–	0.210	0.360	0.553	1.037	1.587	1.870	3.903	2.420
		–	–	0.036	0.010	0.098	0.029	0.139	0.241	0.340	–
Clavicle Bone		–	–	0.290	0.515	0.880	1.503	2.113	2.420	3.307	2.430
		–	–	0.045	0.045	0.084	0.110	0.118	0.046	0.236	–
Total Keel (with		–	–	3.437	6.685	8.853	17.167	24.640	26.460	30.077	27.270
cartilage)		–	–	0.357	0.065	0.502	0.589	1.657	1.051	2.409	–
Keel Bone Only		–	–	2.517	4.880	6.897	13.470	18.203	20.990	24.307	26.000
		–	–	0.285	0.110	0.615	0.415	1.197	0.861	2.083	–

This table derived from the raw data in appendix B.

3.9.1.1 Total Length of the Keel (with cartilage)

- Absolute Total Length of the Keel

The two sets of data from control and selected chickens are plotted in figures 3.16 and 3.17 respectively. There were not significantly different, as shown in figure 3.18.

- Relative Total Keel Length to Live Body Weight

Since the development of the keel is related to the development of the breast

Table 3.23 — Result of Regression Analysis of Different Bone Lengths and Weights on Body Weight in Control Chickens 1–70 Days of Age

		Y-Intercept a	Growth Coeffiecent b ± SE ¶	R^2	F-test† at d.f.=14	t-test‡ at d.f.=14
Clavicle Weight		− 2.7555	0.8429 ± 0.0768	0.9525	–	
Clavicle Length	R	0.4334	0.3752 ± 0.0410	0.9934	N.S.	N.S.
	L	0.4287	0.3771 * ± 0.0159	0.9894		
Coraciod Length	R	0.4285	0.3862 * ± 0.0149	0.9912	N.S.	N.S.
	L	0.3703	0.4048 * ± 0.0266	0.9815		
Coraciod Weight	R	− 3.3143	1.1601 ± 0.0664	0.9807	N.S.	N.S.
	L	− 3.3014	1.1576 ± 0.0699	0.9785		
Posterior X. Process Length	R	0.2248	0.4482 ** ± 0.0161	0.9923	N.S.	N.S.
	L	0.2036	0.4534 *** ± 0.0173	0.9914		
Posterior X. Process Weight	R	− 3.6852	1.0915 ± 0.0428	0.9909	N.S.	N.S.
	L	− 3.7395	1.1029 * ± 0.0314	0.9952		
Anterior X. Process Length	R	0.1007	0.4204 ** ± 0.0192	0.9876	N.S.	N.S.
	L	0.0311	0.4421 ** ± 0.0261	0.9795		
Keel Height	R	0.0363	0.4340 * ± 0.0275	0.9765	N.S.	N.S.
	L	0.0158	0.4399 ** ± 0.0265	0.9787		
Total Keel Length		0.6212	0.4113 ** ± 0.0148	0.9961	–	
Bone Keel Length		− 0.1015	0.4754 ± 0.1071	0.7667	–	
Total Keel Weight		− 2.3899	1.0663 ± 0.0407	0.9914	–	
Bone Keel Weight		− 2.5598	1.0763 ± 0.0355	0.9942	–	
Dorsal Keel Width		0.0548	0.3676 ± 0.0194	0.9836	–	

¶ Number of asterisks indicate allometric coefficient significantly different from the unit at 0.05(*), 0.01(**), and 0.001(***) level.

‡ F-test to determine whether there is difference between the two regressions or not.

‡ t-test to determine whether the slopes of the two date differ or not.

Table 3.24 — Result of Regression Analysis of Different Bones Lengths and Weights on Body Weight in Selected Chickens 20–70 Days of Age

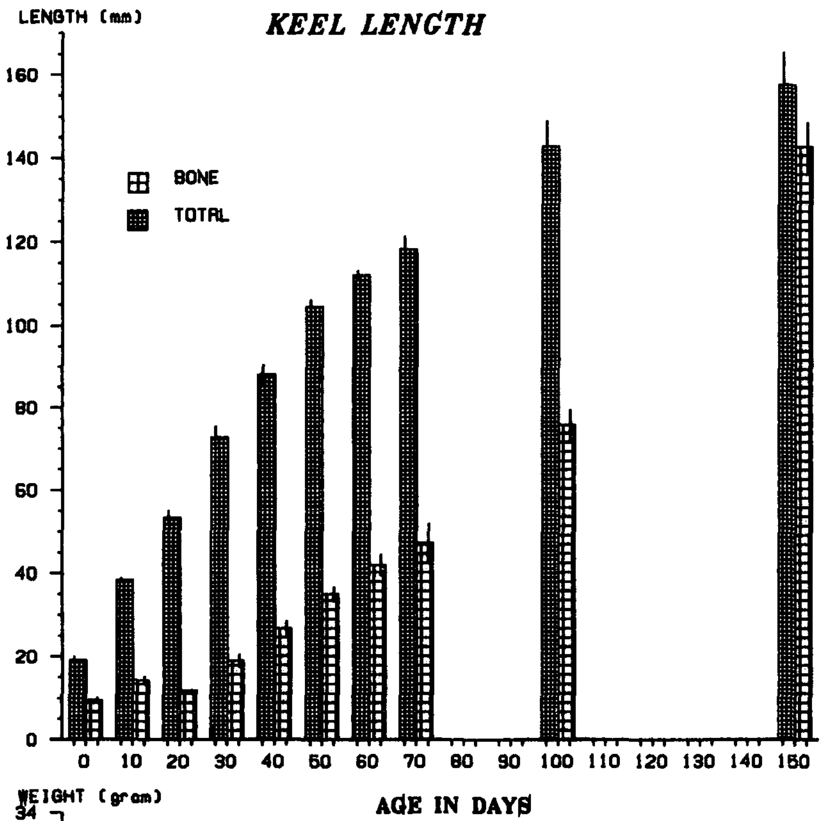
		Y-Intercept a	Growth Coeffiecent b ± SE ¶	R^2	t-test† at d.f.=10	F-test‡ at d.f.=10
Clavicle Weight		− 2.7555	0.8429 ± 0.0768	0.9525	-	
Clavicle Length	R	0.5890	0.3128 ± 0.0195	0.9846	N.S.	N.S.
	L	0.6162	0.3050 ± 0.0131	0.9926		
Coraciod Length	R	0.7057	0.3030 ± 0.0273	0.9685	N.S.	N.S.
	L	0.6382	0.3223 ± 0.0205	0.9840		
Coraciod Weight	R	− 2.1379	0.8039 * ± 0.0701	0.9676	N.S.	N.S.
	L	− 2.2339	0.8358 * ± 0.0430	0.9895		
Posterior X. Process Length	R	0.5375	0.3520 ± 0.0367	0.9583	N.S.	N.S.
	L	0.5759	0.3395 ± 0.0342	0.9610		
Posterior X. Process Weight	R	− 3.3686	1.0040 ± 0.0737	0.9789	N.S.	N.S.
	L	− 3.3573	0.9952 ± 0.0622	0.9846		
Anterior X. Process Length	R	0.2283	0.3776 ± 0.0515	0.9308	N.S.	N.S.
	L	0.2161	0.3820 ± 0.0278	0.9791		
Keel Height	R	0.2520	0.3669 ± 0.0187	0.9897	N.S.	N.S.
	L	0.2221	0.3760 ± 0.0235	0.9846		
Total Keel Length		0.8287	0.3455 ± 0.0235	0.9818	-	
Bone Keel Length		− 0.7415	0.6817 ** ± 0.0464	0.9818	-	
Total Keel Weight		− 1.9431	0.9313 ± 0.0404	0.9913	-	
Bone Keel Weight		− 2.1509	0.9586 ± 0.0316	0.9957	-	
Dorsal Keel Width		0.0326	0.3821 ± 0.0303	0.9755	-	

¶ Number of asterisks indicate allometric coefficient significantly different from the unit at 0.05(*), 0.01(**), and 0.001(***) level.

‡ F-test to determine whether there is difference between the two regressions or not.

‡ t-test to determine whether the slopes of the two date differ or not.

FIGURE 3.16 TOTAL AND BONE KEEL IN CONTROL CHICKENS



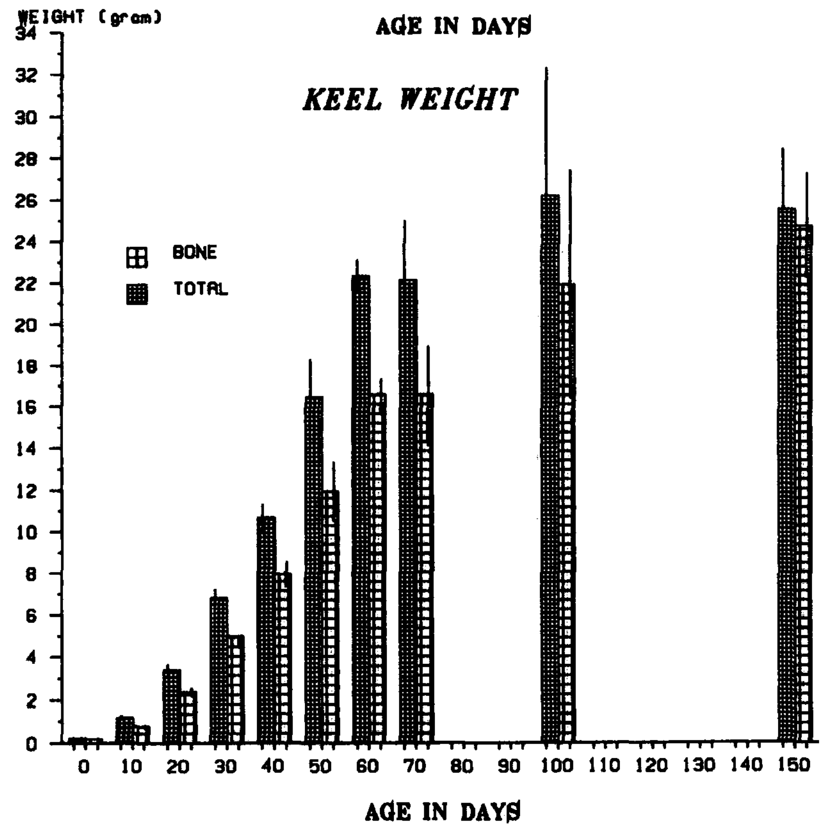


FIGURE 3.17 TOTAL AND BONE KEEL IN SELECTED CHICKENS

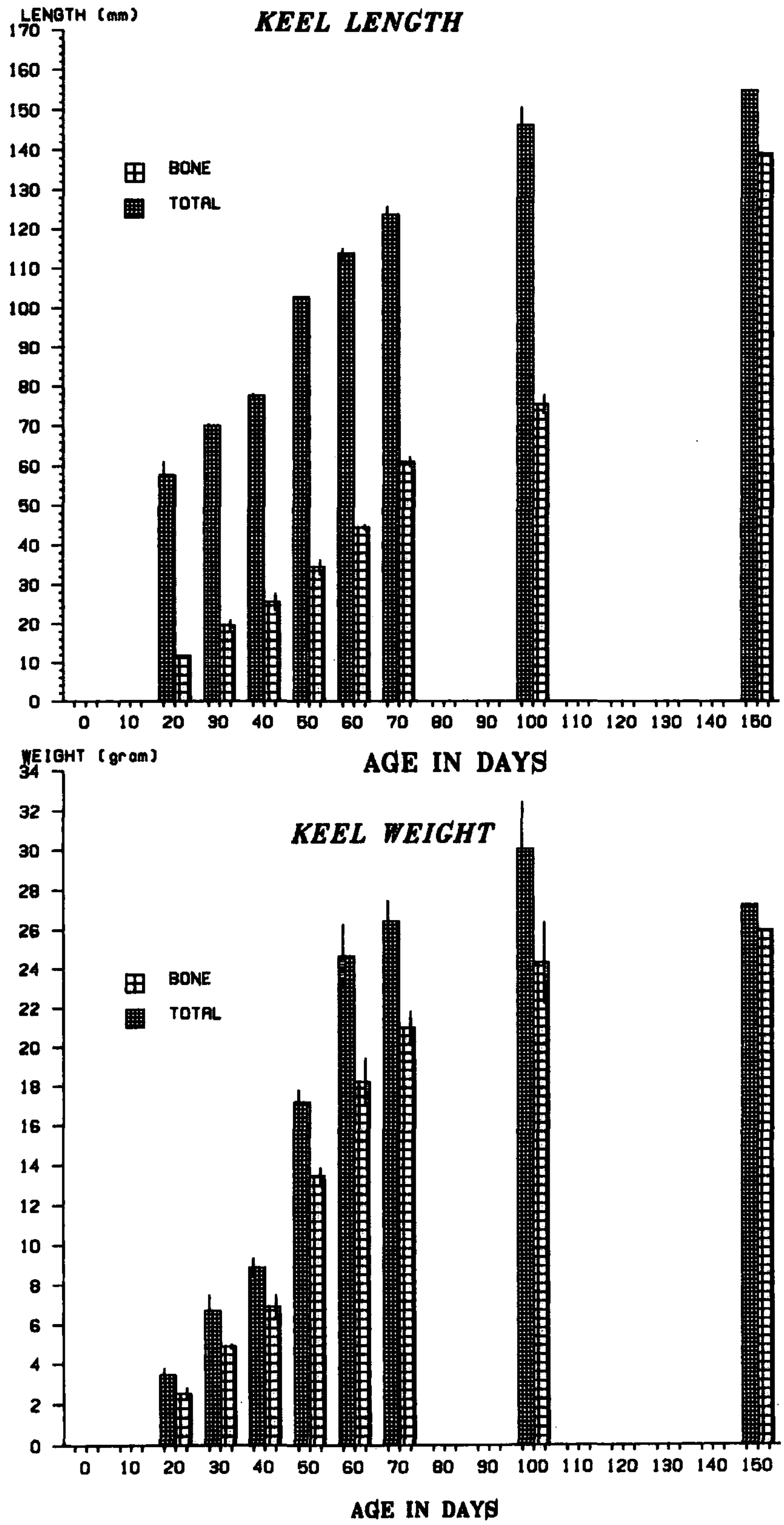
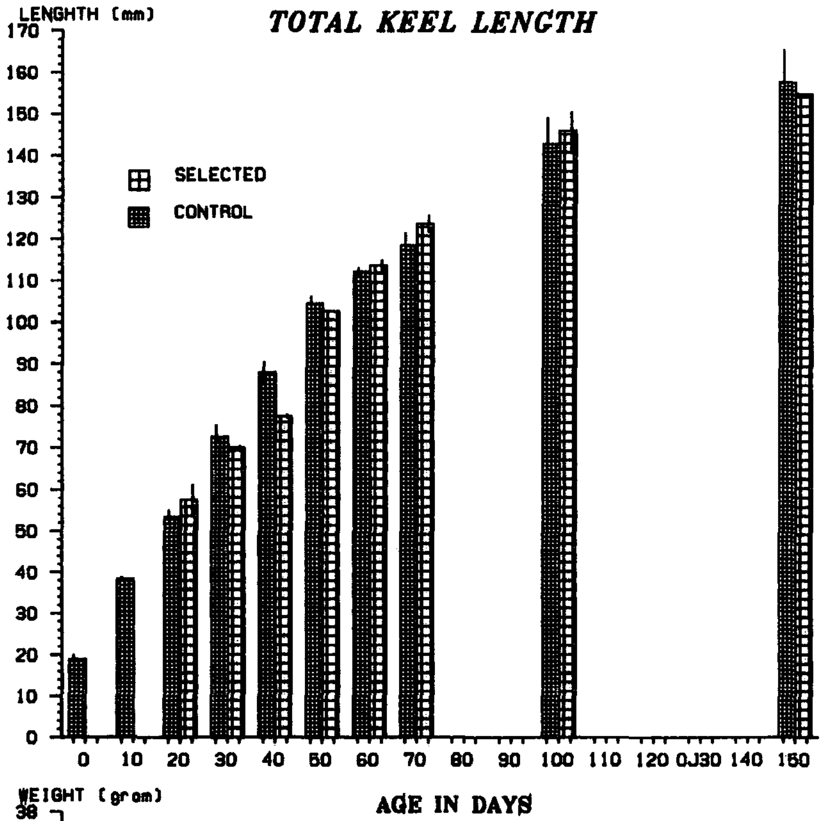
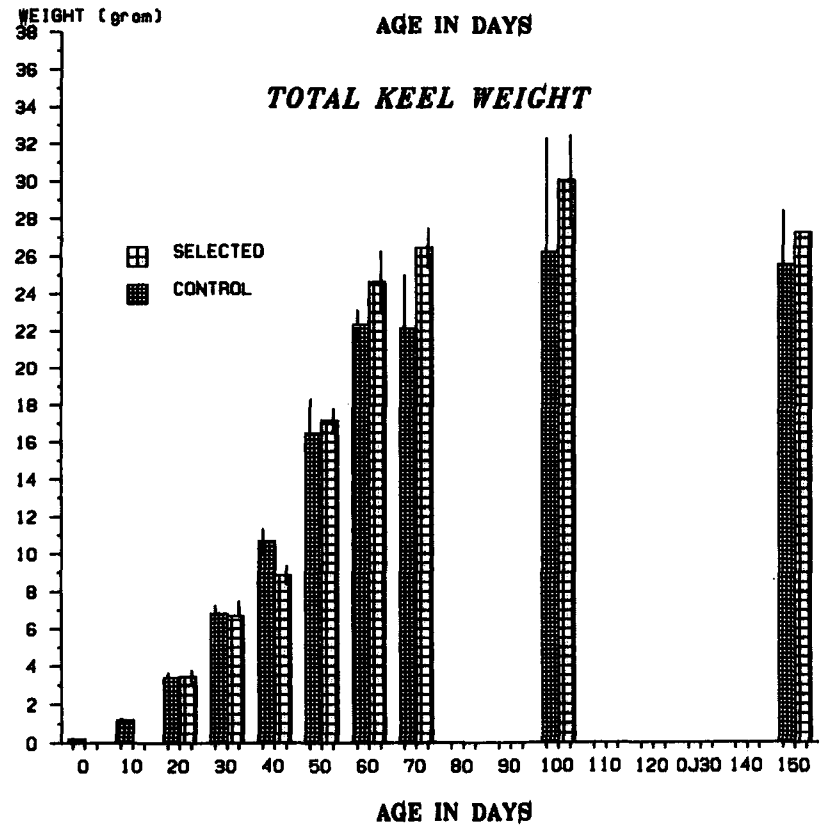


FIGURE 3.18 TOTAL KEEL LENGTH AND WEIGHT IN CONTROL AND SELECTED CHICKENS





muscles as mentioned above, therefore, growth of the total keel length was studied in relation to the live body weight with age. Here, control chickens had a significantly ($t = 2.486$, $p < 0.05$) higher allometric growth coefficient than the selected chickens, although selected chickens were heavier in live body weight and pectoralis muscles weight. As a result the two regression lines (slopes) were not parallel or identical which means that selected chickens had shorter total keel lengths than controls in relation to their body weight, and their keels were growing more slowly than control chickens.

3.9.1.2 Length of the Keel Bone Only

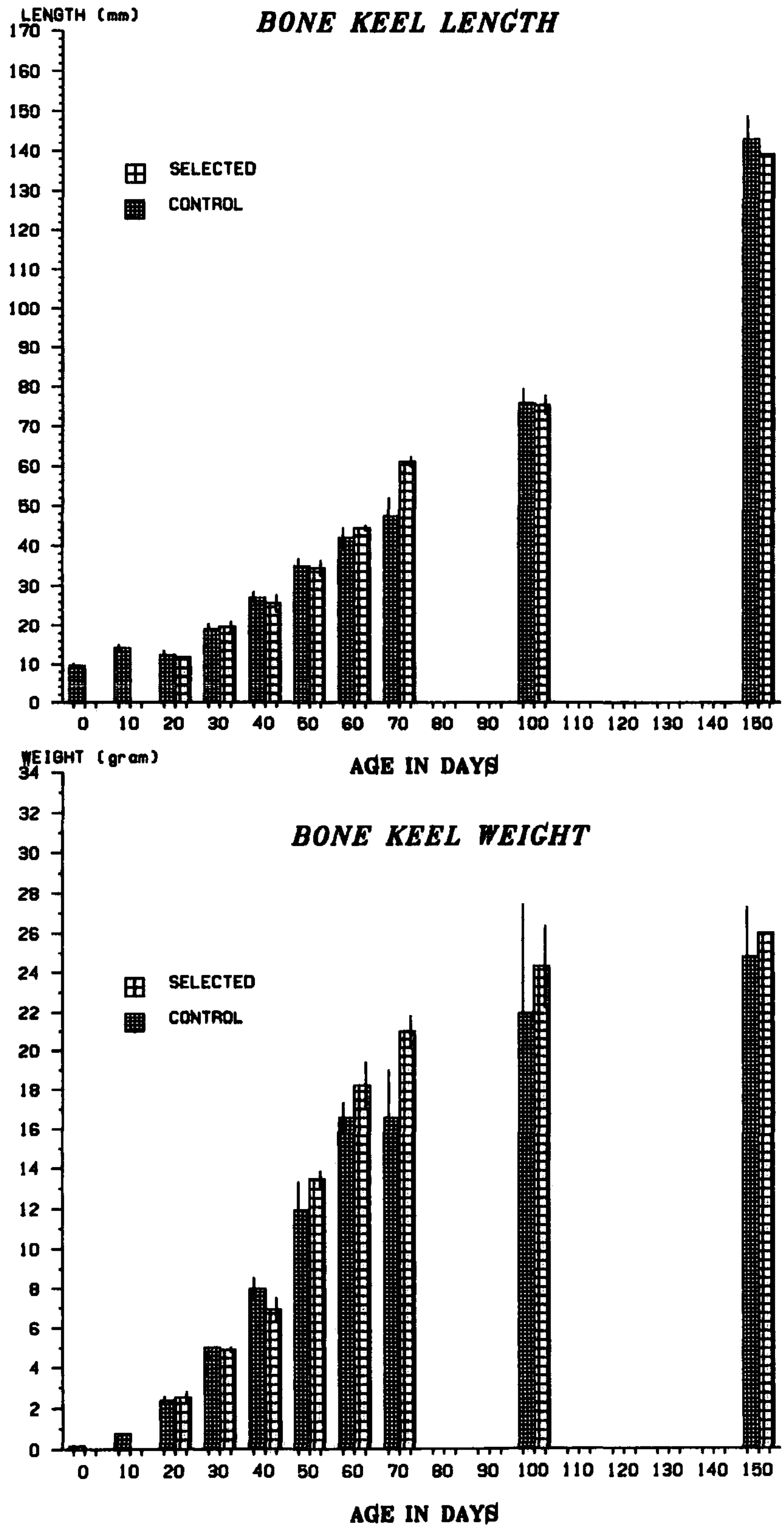
- Absolute Length of the Keel Bone

There was no significant difference in the keel bone length between the control and selected chickens as shown in figure 3.19.

- Relative Length Keel Bone to Live Body Weight

Total keel length in control chickens had a significantly higher allometric growth coefficient on body weight than in selected chickens. As a result, the total keel length in control chickens was growing faster than the live body weight, but the allometric growth coefficient of the keel *bone* length was not significantly different from 0.333. In selected chickens, however, the allometric growth coefficient was very significantly different from 0.333 and the keel bone length was growing faster than the live body weight. As a result, control chickens had significantly longer keel cartilage length which made the total keel length in control chicken significantly different in their allometric growth coefficient in relation to the body weight.

FIGURE 3.19 BONE KEEL LENGTH AND WEIGHT IN CONTROL AND SELECTED CHICKENS



3.9.1.3 Total Keel Weight

- Absolute Total Weight

Student's t-test revealed that there was no significant difference between control and selected chickens in their total keel weight (Figure 3.18).

- Relative Total Keel Weight to Live Body Weight

In the relation of total keel weight to live body weight, control chickens had a significantly ($t = 2.30$, $p < 0.05$) larger allometric growth coefficient than selected chickens as shown in tables 3.23 and 3.24. But neither regression line was significantly different from one. Thus the total keel weight in both control and selected chickens was growing in proportion to the live body weight.

3.9.1.4 Keel Bone Weight

- Absolute Keel Bone Weight

Student's *t*-test revealed that the absolute keel bone weights of control and selected chickens were not significantly different, as shown in figure 3.19.

- Relative Keel Bone Weight to Live Body Weight

The allometric growth coefficient in both control and selected chickens was not different from one. Moreover, the two allometric growth coefficients in both control and selected chickens were not significantly different.

3.9.1.5 Dorsal Keel Width

- Absolute Dorsal Keel Width

There was no significant difference between the absolute keel width of the control and selected chickens as shown in figure 3.20.

- Relative Growth of Dorsal Keel Width to Live Body Weight

The allometric growth coefficients of the dorsal keel width are not different from 0.333in either control or selected chickens. Thus dorsal keel width was growing isometrically with respect to live body weight in both control and selected chickens.

3.9.1.6 Keel Height

At the anterior end of the sternum, measurement was taken from each side (right and left) of the keel to represent the keel height as illustrated in figure 2.8, plate 2.35 in chapter II. Data were studied as follows:

- Absolute Keel Height

There was no significant difference in the keel height between the right and the left side of the keel either in control or selected chickens. However, comparison between each side in control with its corresponding side in selected chickens, revealed some significant differences. At age 70 days, selected chickens had significantly higher keel height ($t = 4.431$, $p < 0.05$; $t = 4.446$, $p < 0.05$) for the right and the left side than the control chickens as shown in tables 3.19 and 3.20. At age 30 days, the right side of the keel in selected chickens was significantly ($t = 3.421$, $p < 0.05$) lower in height than control chickens (see figure 3.21).

FIGURE 3.20 – DORSAL WIDTH OF THE KEEL IN CONTROL AND SELECTED CHICKENS

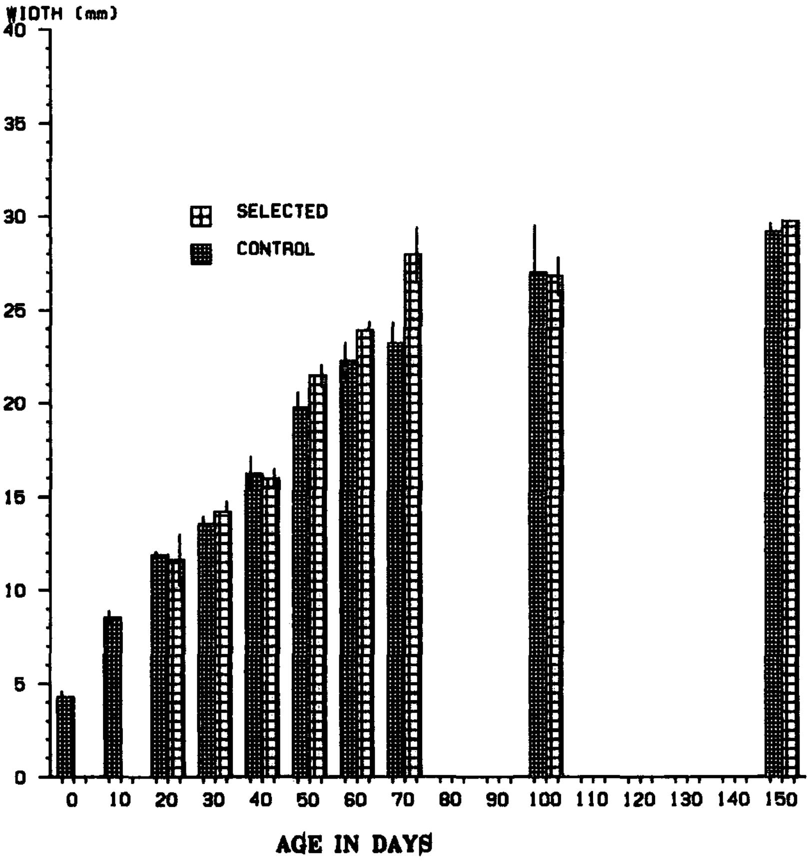
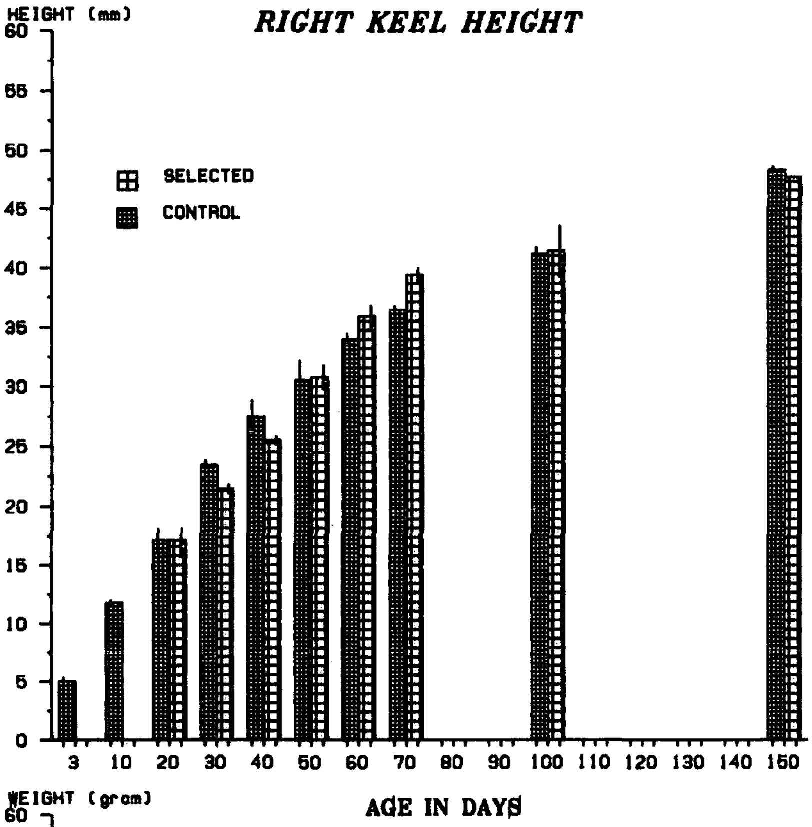
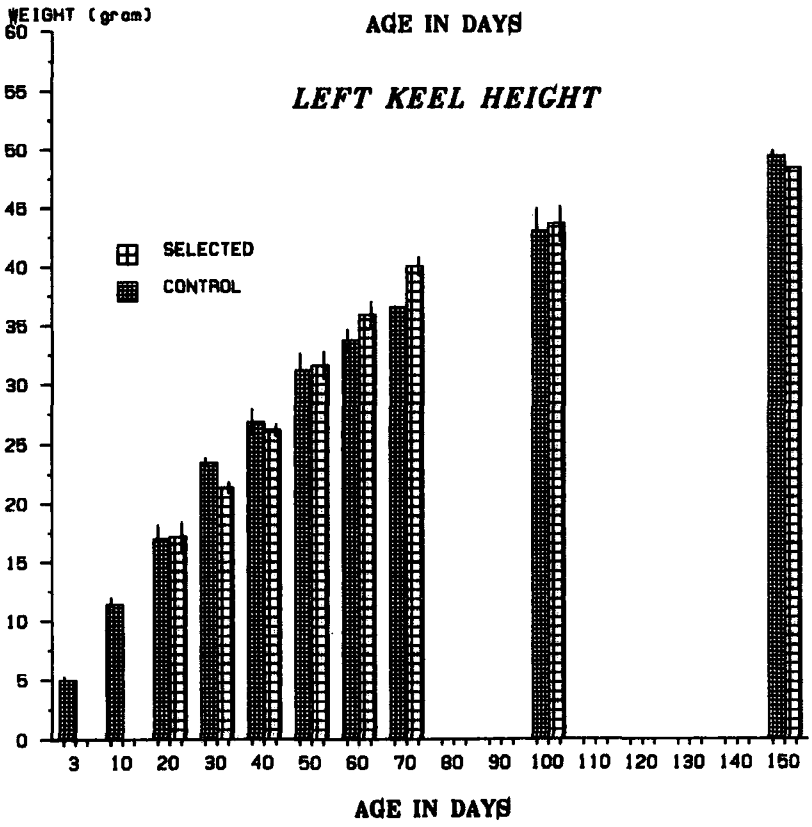


FIGURE 3.21 HEIGHT OF THE KEEL IN CONTROL AND SELECTED CHICKENS





- Relative Growth of Keel Height to Live Body Weight

Keel height growth in relation to live body weight had allometric growth coefficients significantly different from 0.333 at each side in the control chickens (see table 3.23), whereas the allometric growth coefficient in the selected chickens was not significantly different from 0.333 as shown in table 3.24. However, neither

3.9.1.7 Anterior and Posterior Xiphisternal Process

Anterior and *Posterior Xiphisternal Processes,* (A.X. process and P.X. process) are the two pairs of backwardly directed structures of the sternum which help to support the viscera and the pectoralis muscle (see figures 2.3 and 2.6, plate 2.2 and 2.3). Thus it was necessary to study their growth and development. Data are presented in tables 3.19 and 3.20 and tables 3.21 and 3.22 and are plotted in figures 3.22 and 3.23 for their lengths and weights respectively in control and selected chickens.

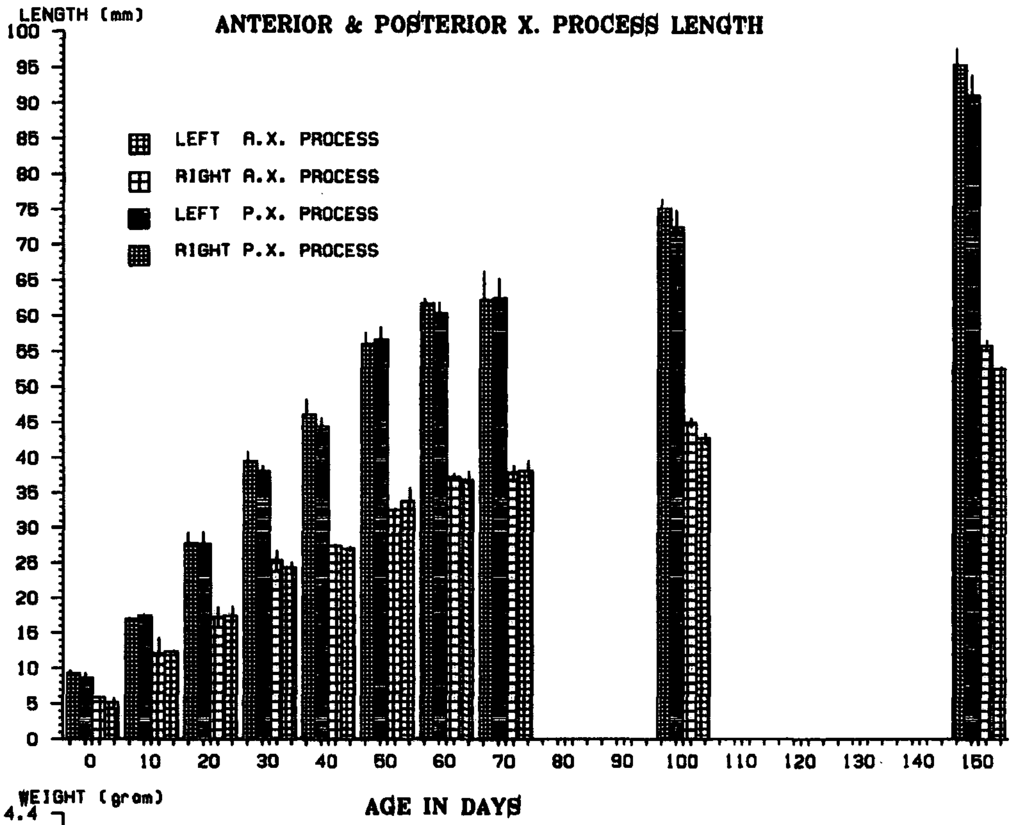
1. Anterior Xiphisternal Process

- The Absolute Length

There was no significant difference between the two sides either in control or selected chickens. Furthermore, Student's t-test was carried out to compare each side of the control chickens with its corresponding one in selected chickens. The result revealed that the right and left A.X. processes in selected chickens at 70 and 100 days of age, were significantly (right: $t = 3.728$, $p < 0.05$, $t = 5.689$, $p < 0.01$: left; $t = 3.874$, $p < 0.05$ and $t = 7.615$, $p < 0.01$ respectively) longer than the control chickens.

- Relative Growth of A.X. Process to Live Body Weight

FIGURE 3.22 ANTERIOR AND POSTERIOR X. PROCESS IN CONTROL CHICKENS



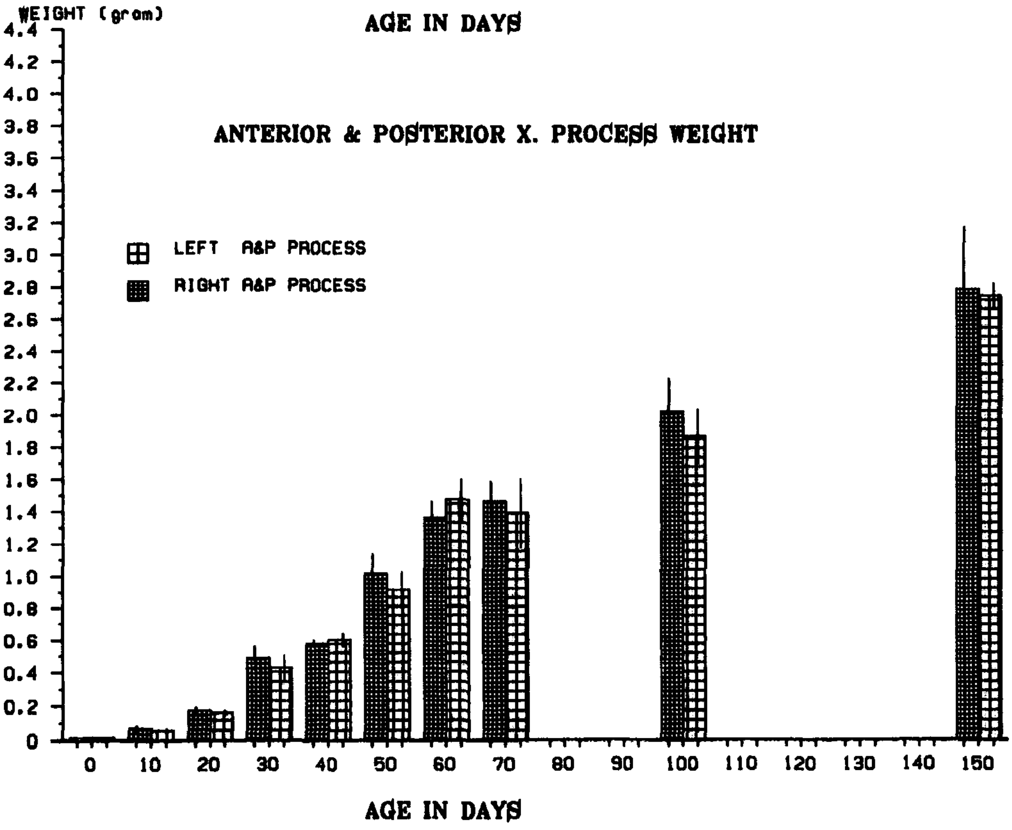
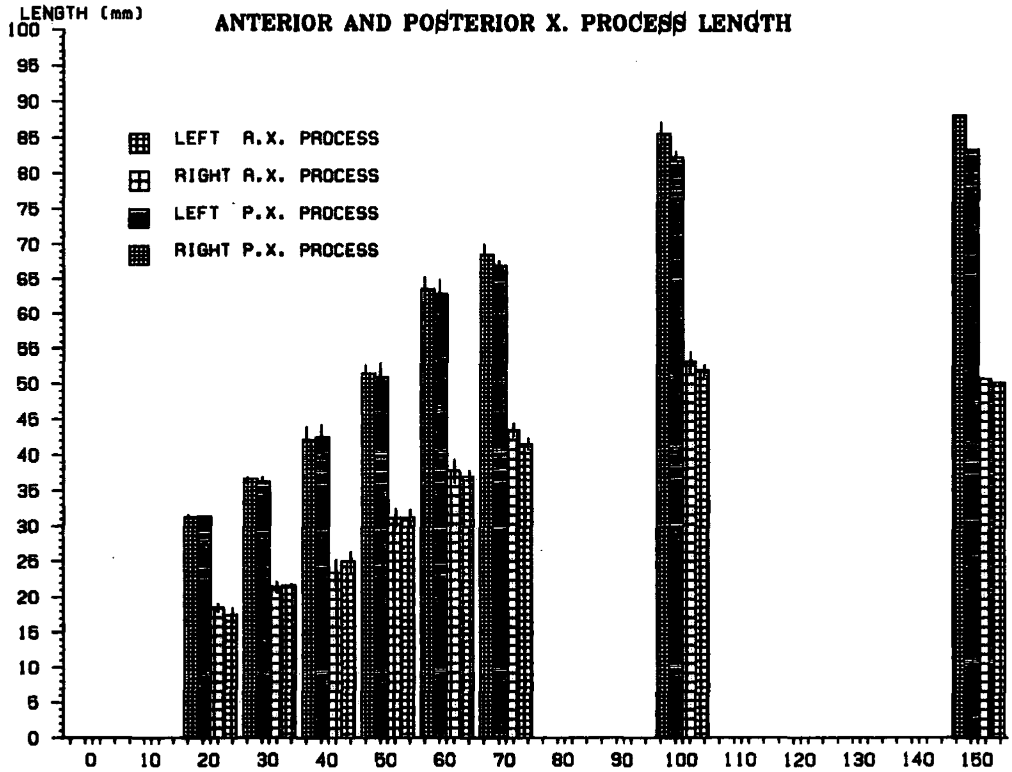
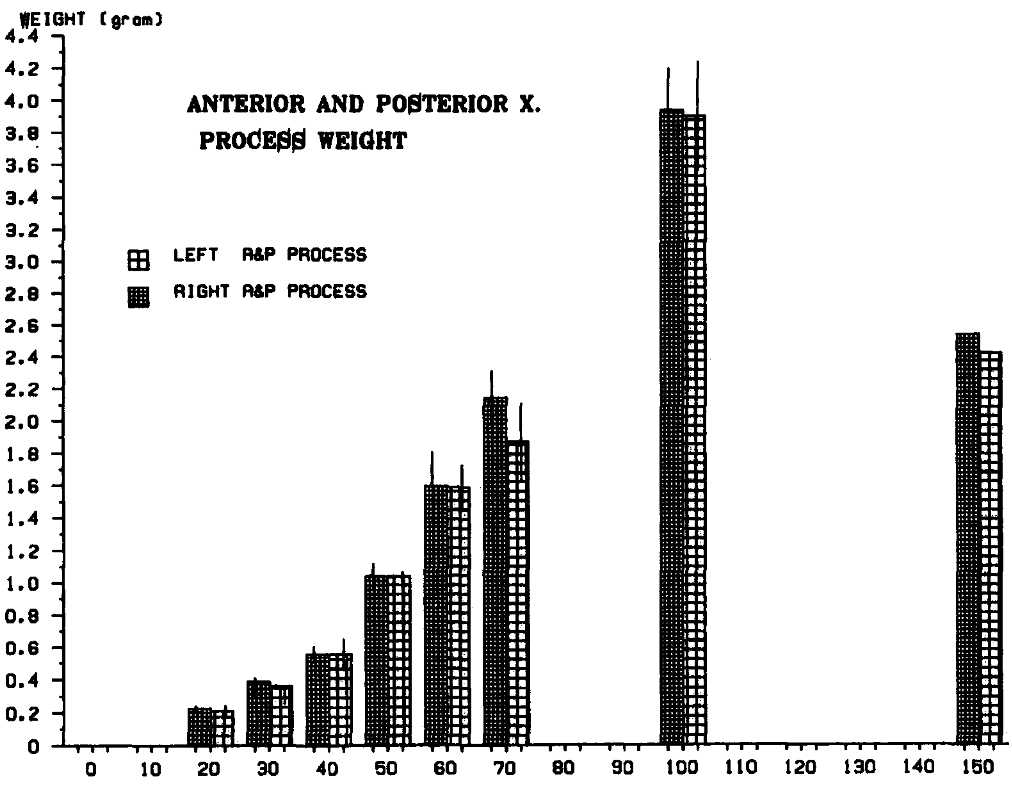


FIGURE 3.23 ANTERIOR AND POSTERIOR X. PROCESS IN SELECTED CHICKENS





The allometric growth coefficient A.X. process in control chickens was significantly different from 0.333 for both sides, but it was not significantly different in the selected chickens. No significant differences were obtained between the two sides, or between each side of the control to its corresponding one in selected chickens.

2. Posterior Xiphisteral Process

- Absolute Length of P.X. Process

There was no significant difference between the right and the left side within control or selected chickens. Also, each side of the control chickens was not significantly different to its corresponding side in selected chickens except at age 100 days, where selected chickens had an average length of P.X. process of the right side significantly ($t = 4.877$, $p < 0.05$) longer than the control right side.

- Relative Growth of P.X. Process Length to Live Body Weight

Allometric growth coefficient of P.X. process on live body weight in control chickens was significantly different from 0.333, but it was not in the selected chickens.

The differences between the right and the left side were not significant either in control or selected chickens. But the differences between each side of the control to its corresponding side in selected chickens were significantly different. The right P.X. Process in selected chickens had a significantly smaller allometric growth coefficient ($t = 2.633$, $p < 0.05$) than control chickens. Also, on top of that, the two regression lines (slopes) were not parallel ($F = 6.136$, $p < 0.05$), which means that P.X. process length in the selected chickens was growing, in relation to live body weight, slower than the controls. On the other hand, the left P.X. process in the selected chickens also had significantly smaller allometric growth coefficient

($t = 3.209$, $p < 0.01$) than control chickens, and the two slopes were significantly different ($F = 8.405 < 0.05$), therefore the two regression lines were not parallel.

The conclusion for the P.X. process is that the P.X. process in control chickens were growing in length in both sides faster than in the selected chickens.

- Absolute Anterior and Posterior X. Process Weight

Anterior X. process and posterior X. process were weighed together and the average weight of each age group in control and selected chickens is presented in tables 3.21 and 3.22 and data plotted in figures 3.22 and 3.23 respectively. There was no significant difference in weight between the two sides in control or selected chickens.

- Relative Growth of A.X. Process Weight to Live Body Weight

Allometric growth coefficient of the left side in control chickens was significantly different from one ($p < 0.05$) whereas in the selected chickens the allometric growth coefficient was not significantly different from one.

Their were no significant differences between the right and the left side, nor between each side in the control to its corresponding side in selected chickens. Therefore all the slopes were parallel and identical.

3.9.2 The Pectoral Girdle

There are three bony elements in the *pectoral girdle* on each side, the sabre-shaped *scapula,* the *coracoid* and the *clavicle* (see figure 2.4, plate 2.2). At the beginning of this research, no measurements were taken on the scapula because it is not attached to the pectoralis muscles. In the following chapters, the scapula was considered with the rib cage to which it is closely bound by muscle and ligaments.

The coracoid and clavicle act as struts holding the wing away from the body. The clavicles are slender bones fused to a median ventral piece, the *interclavicle,* giving the V-shaped *furcula* or 'wishbone' (Ede, 1968). At its posterior end it is very firmly articulated with the sternum between the rostrum and the costal process, and anterior end, each coracoid is fused with the *acromion process* of the scapula. A ligamentous membrane connects the coracoid to the clavicle along its length, and a sternoclavicular ligament joints the interclavicle to the sternum (see Figure 2.4, plate 2.2).

Length and weight of these bones were recorded, and the data are presented in tables 3.19, 3.20, 3.21, and 3.22.

1. The Clavicle Bones

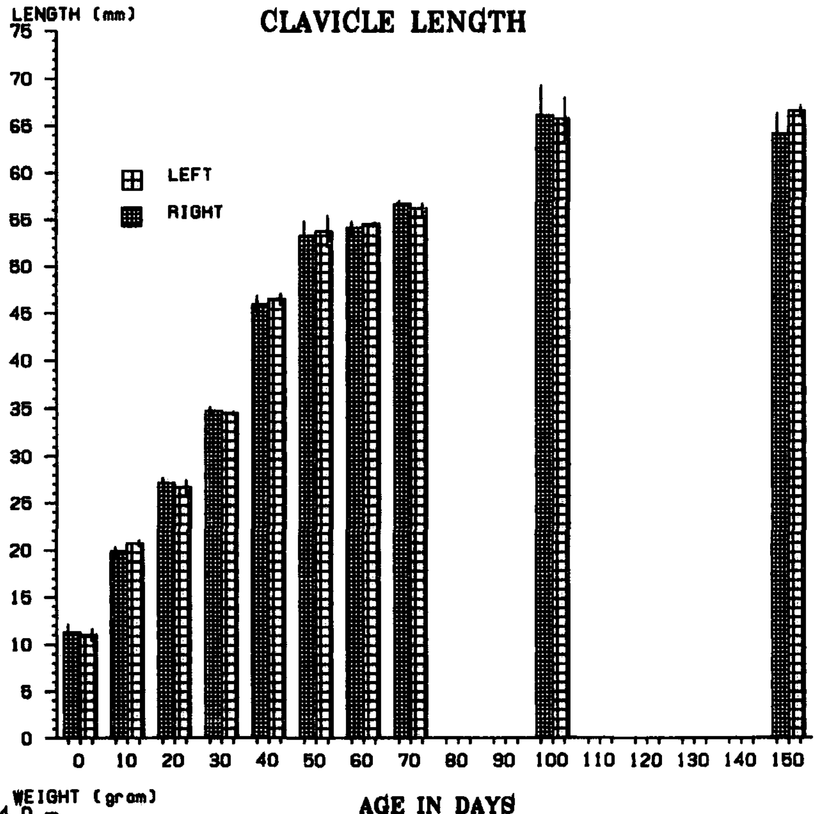
- Absolute Clavicle Length

The two sides of the clavicle were growing similarly in length in both control and selected chickens (figures 3.24 and 3.25). But corresponding length of the clavicle in control and selected chickens showed some significant differences. The right clavicle length in control chickens was significantly longer ($t = 7.161$, $p < 0.01$; $t = 3.214$, $p < 0.05$; $t = 3.341$, $p < 0.05$) at age 40, 50 and 60, respectively, than the right of selected chickens. On the other side, the left clavicle length in control chickens, also was significantly longer at the above ages than the selected chickens ($t = 9.205$, $p < 0.001$; $t = 4.854$, $p < 0.01$; and $t = 3.735$, $p < 0.05$).

- Absolute Clavicle Weight

The clavicle weight included the right and the left clavicle and interclavicle. Control and selected chickens were not significantly different in their clavicle weight

FIGURE 3.24 - CLAVICLE BONE IN CONTROL CHICKENS



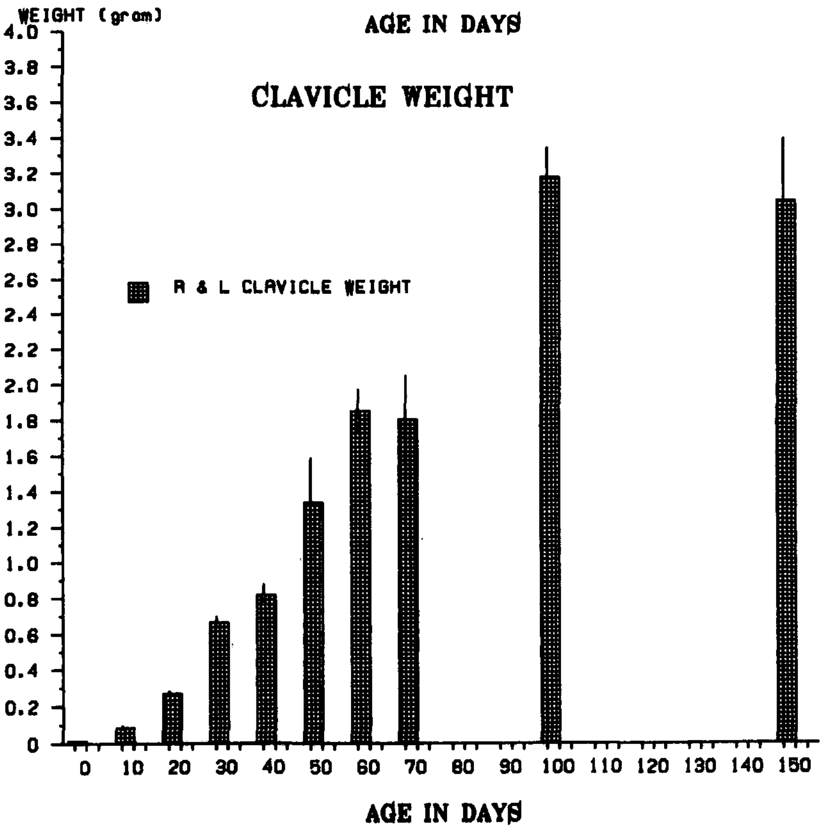
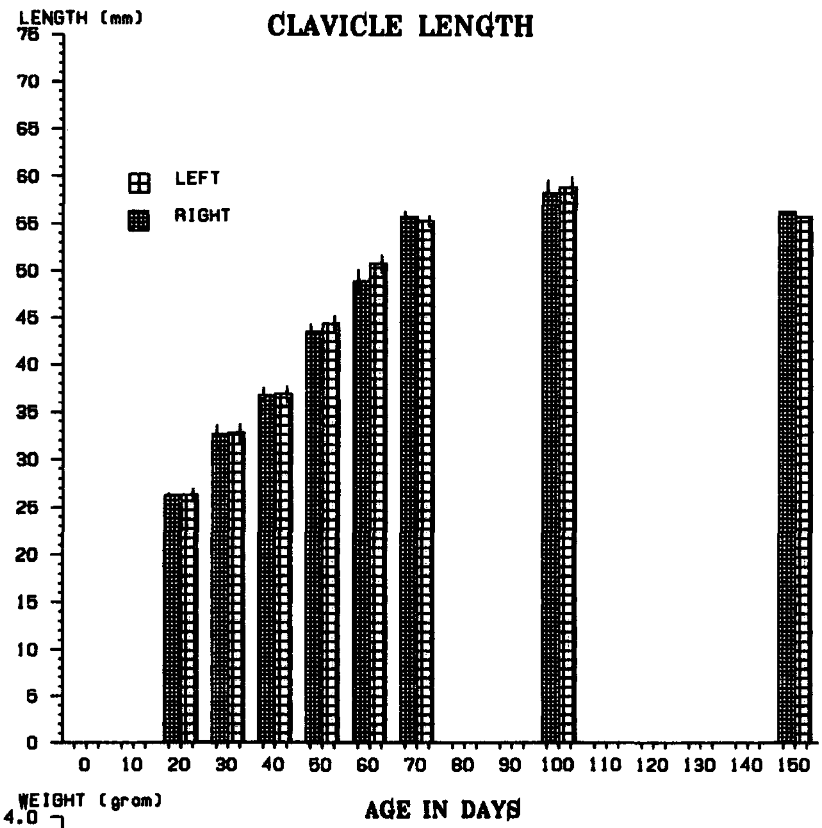
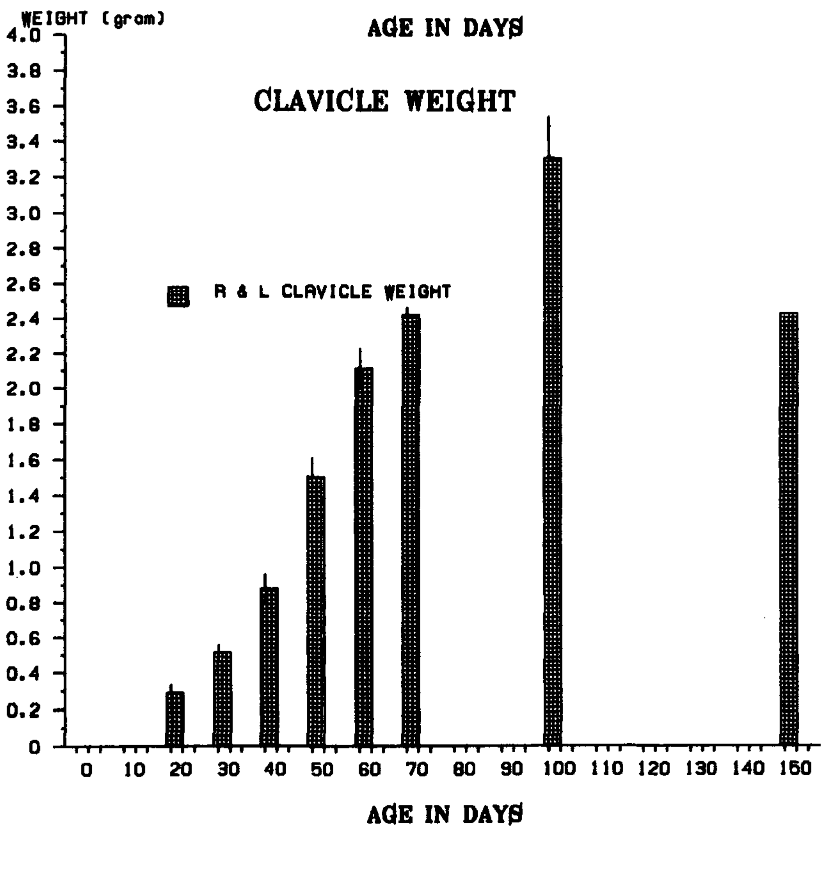


FIGURE 3.25 CLAVICLE BONE IN SELECTED CHICKENS





although control chickens had significantly longer clavicles as was mentioned above (see figures 3.24 and 3.25).

- Relative Growth of Clavicle Bone Length to Live Body Weight

Clavicle bone length was studied in relation to live body weight in control and selected chickens. Result of regression analysis is given in tables 3.23 and 3.24 for control and selected chickens respectively. The differences in allometric growth coefficient between the right and the left clavicles length were not significant in the control or selected chickens. However, the allometric growth coefficient of the left side of the selected chickens was significantly ($t = 3.328$, $p < 0.01$) smaller than the control chickens. Thus the selected slope (of the left side) was not parallel to the controls ($F = 5.599$, $p < 0.05$). So the selected chickens had a small allometric growth coefficient at the left side of the clavicle bone length.

- Relative Growth of Clavicle Bone Weight to Live Body Weight

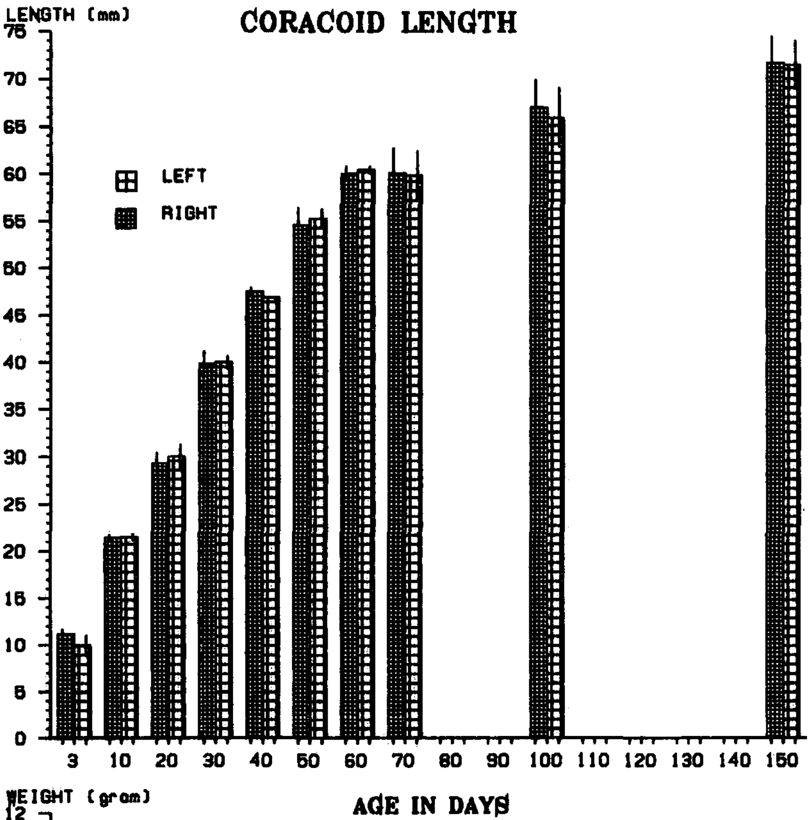
Clavicles were not significantly different in their absolute weight in control and selected chickens. Result of regression analysis given in tables 3.23 and 3.24 shows that allometric growth coefficients of clavicle weight on body weight were not significantly different from one in the control or selected chickens. Also, no significant differences were obtained between control and selected chickens in their allometric growth coefficient.

2. The Coracoid Bone

- Absolute Coracoid Bone Length

There were no significant differences in length between the right and left bone in control or selected chickens as shown in figures 3.26 and 3.27 respectively.

FIGURE 3.26 CORACOID BONE IN CONTROL CHICKENS



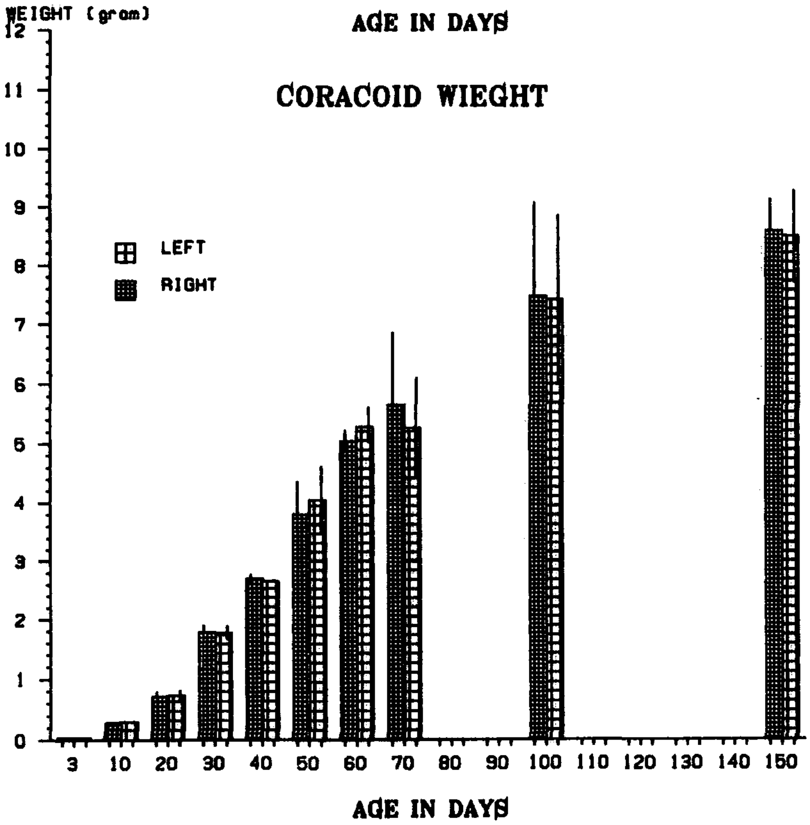
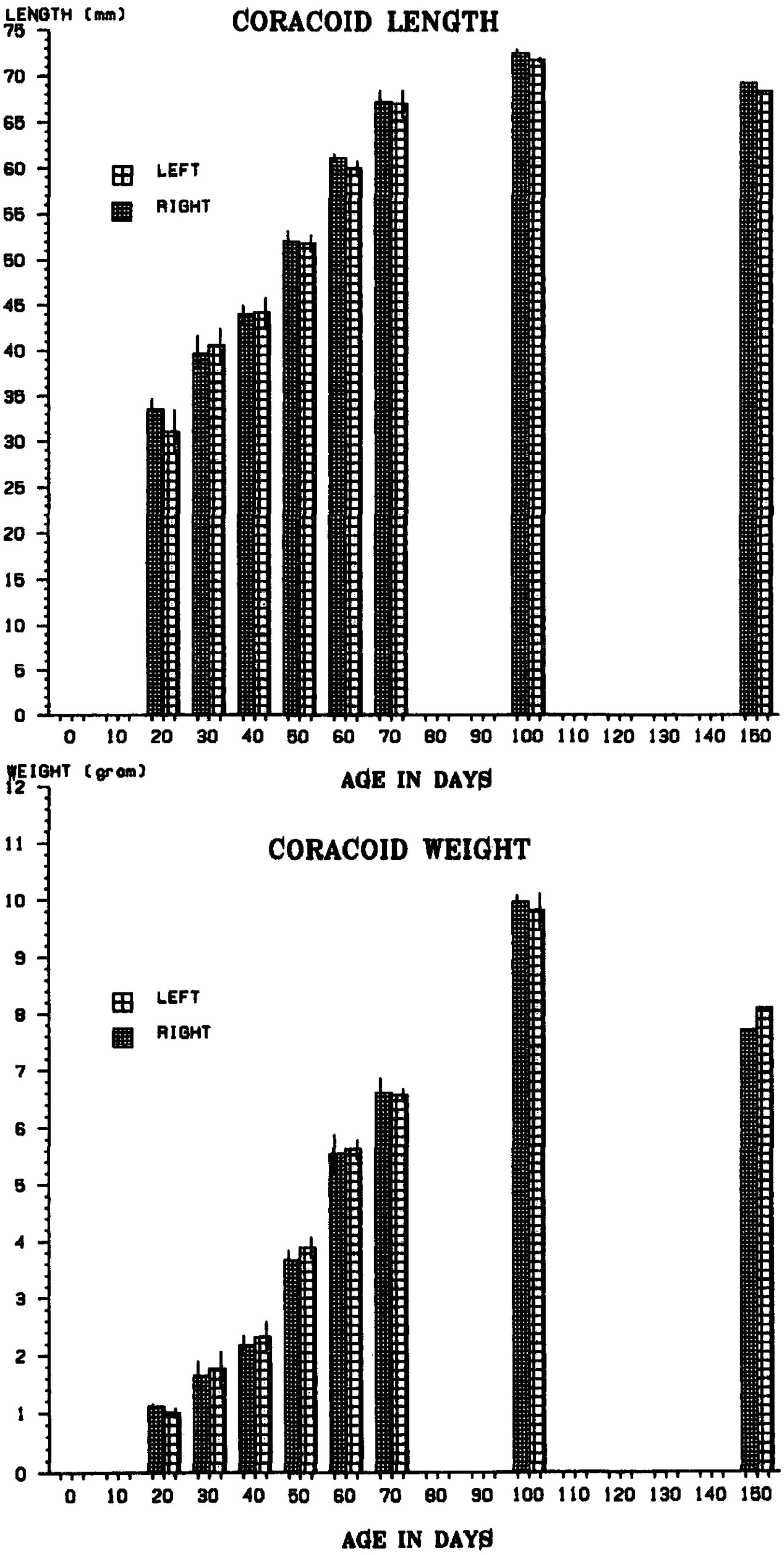


FIGURE 3.27 CORACOID BONE IN SELECTED CHICKENS



Also, there was no significant difference between each side of the control and its corresponding side in selected chickens, except at age 40, where the control chickens had significantly larger average coracoid length at the right side ($t = 3.211$, $p < 0.05$) than the selected chickens.

- Absolute Coracoid Bone Weight

There was no significant difference between the two sides in control or selected chickens. In addition, the difference between each side of control to its corresponding one in the selected chickens was not significant either.

- Relative Growth of Coracoid Length to Live Body Weight

Control chickens had significantly ($t = 2.861$, $p < 0.05$ and $t = 2.315$, $p < 0.05$) higher allometric growth coefficient of coracoid length on the right and the left sides than the selected chickens. Furthermore, the allometric growth coefficients of selected chickens were not significantly different from 0.333, whereas the right and left coracoid in control chickens were significantly different from 0.333 ($t = 3.550$, $p < 0.05$; and $t = 4.312$, $p < 0.01$ respectively).

- Relative Growth of Coracoid Weight to Live Body Weight

The allometric growth coefficient of the right and left coracoid bone weights in control chickens were not significantly different from one, whereas selected chickens had significantly different allometric growth coefficient from one as shown in tables 3.23 and 3.24. However, the differences between the right and left sides were not significant in either the control or selected birds. Student's t-test was carried out to compare each side of the control to its corresponding side in selected chickens. Allometric growth coefficient of the right and left side of the control chickens was very significantly ($t = 3.640$, $p < 0.01$; and $t = 6.598$, $p < 0.01$ respectively) different from the their corresponding side in the selected chickens, even so the slopes were not parallel too ($F = 7.512$, $p < 0.05$; and $F = 8.946$, $p < 0.01$ respectively).

It was concluded, that selected chickens had faster bone growth , but in relation to the body weight their bones were shorter and lighter than the controls.

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Chapter IV

PECTORALIS MUSCLE ARCHITECTURE

4.1 Introduction

Skeletal muscles typically consist of varying proportions of different fibre types, which have distinctive structural, physiological and biochemical characteristics (Morgan and Proske 1984; Johnston 1985; Perry 1985). The relationship between the structure and function of avian muscle fibre types was initially revealed through the histochemical demonstration of metabolic differences in the fast-twitch glycolytic (FG or white), fast twitch oxidative-glycolytic (FOG or Intermediate) and slow-twitch oxidative (SO or red) as classified by Peter, *et al.,* 1972. SO fibres, narrow in diameter, myoglobin rich and fat loaded, are adapted primarily for aerobic (oxidative) metabolism for slow, fatigue-resistant contraction, while FG fibres are broad, devoid of myoglobin and fat, anaerobic (glycolytic), fast fatiguing, and adapted for brief, powerful bursts of activity (George and Berger, 1966). FOG fibres were subsequently recognized as being between FG and SO fibres in structural and functional characteristics (see Ogata and Mori 1964; George and Berger 1966).

As broiler body size increases, functional demands on muscles change, causing alteration of muscle structural characteristics. Muscles increase in size by longitudinal growth of existing fibres, by addition of new fibres to increase girth, and by growth in diameter of existing fibres (Helmi and Cracraft, 1977). Selection for increased size or growth rate resulted in increased muscle weight and fibre number in several animals, for example mice (Luff and Goldspink 1967; Byrne *et al.,* 1973; Hanrahan *et al.,* 1973; Aberle and Doolittle 1976), chickens (Smith 1963; Mizuno and Hikami 1971) and quail (Fowler *et al.,* 1980). Greater fibre diameter also contributed to greater muscle weight in some selection experiments (Smith 1963; Luff and Goldspink 1967; Byrne *et al.,* 1973; Hanrahan *et al.,* 1973), but in other studies, fibre diameter was not affected by selection (Aberle and Doolittle 1976) or one fibre type was hypertrophied in selected lines (Fowler *et al.,* 1980).

Swatland (1984) summarized four major factors associated with differences in radial growth of muscle fibres in poultry:

1. whether the muscle is a fast-growing breast muscle or a leg muscle working against body weight;
2. the degree to which the birds have been selected for meat yield;
3. physiological differentiation of muscle fibres; and
4. sex of the bird if sexual dimorphism is well developed.

The purposes of my histochemical study of the pectoralis muscles of broiler chickens were:

1. to determine muscle fibre type and diameter at two locations within each right and left pectoralis muscle of control and selected chickens; and
2. to compare muscle fibre types and diameters in control and selected chickens of different ages .

The standard methods used in the preparation of muscle tissue for the cryostat, and the subsequent treatment of fresh frozen sections for histochemical analysis, have been outlined in Chapter II: General Materials and Methods.

Because the myosin-ATPase reaction has come to be regarded as the most useful to distinguish between muscle fibres, this method was followed for study of the pectoralis muscle of the one-day old control chickens. Careful variation of fixation of the section, or the time, or pH of preincubation prior to assay resulted in identification of only two fibre types, as also reported by Ashmore and Doerr (1971). Therefore, NADH-TR and phosphorylase methods were followed as described in Chapter II. SO fibres were characterized by their small size and high NADH activity, FG as large fibre with low NADH and FOG as small fibres with moderate to high NADH activity. Performance and character of the fibres were listed in table 2.1, while their activities are shown in plate 4.1, figures 4.1A and 4.1B for NADH and phosphorylase enzymes respectively

The distribution of fibre types within the pectoralis muscle was studied in two locations (regions), A and B (see Figure 2.1, plate 2.1), because pectoralis muscle consisted almost entirely of fast-twitch (FOG and FG) fibres in the superficial and posterior side, whereas slow fibres (SO) were of extremely rare occurrence in the superficial side and mid-posterior part of the pectoralis muscle. Rosser and George (1986b) reported that there was a significantly higher proportion of SO fibres in the deep area of the pectoralis muscle. Therefore the two regions, A and B, were chosen to study the distribution of fibre types at different locations in order to study the three fibre types in region A (anterior) and B (mid) part, whereas the extreme posterior part was not studied because it consists only of white (FG) fibres. My study was in agreement with Rosser and George (1986b) who reported a higher proportion of SO fibres in the deepest part (close to the sternum) of the pectoralis muscle in region A. (see Figures 4.2 and 4.3, plate 4.2 and 4.3). This deep, distal, circumscribed area of the pectoralis muscle, termed the deep red strip,

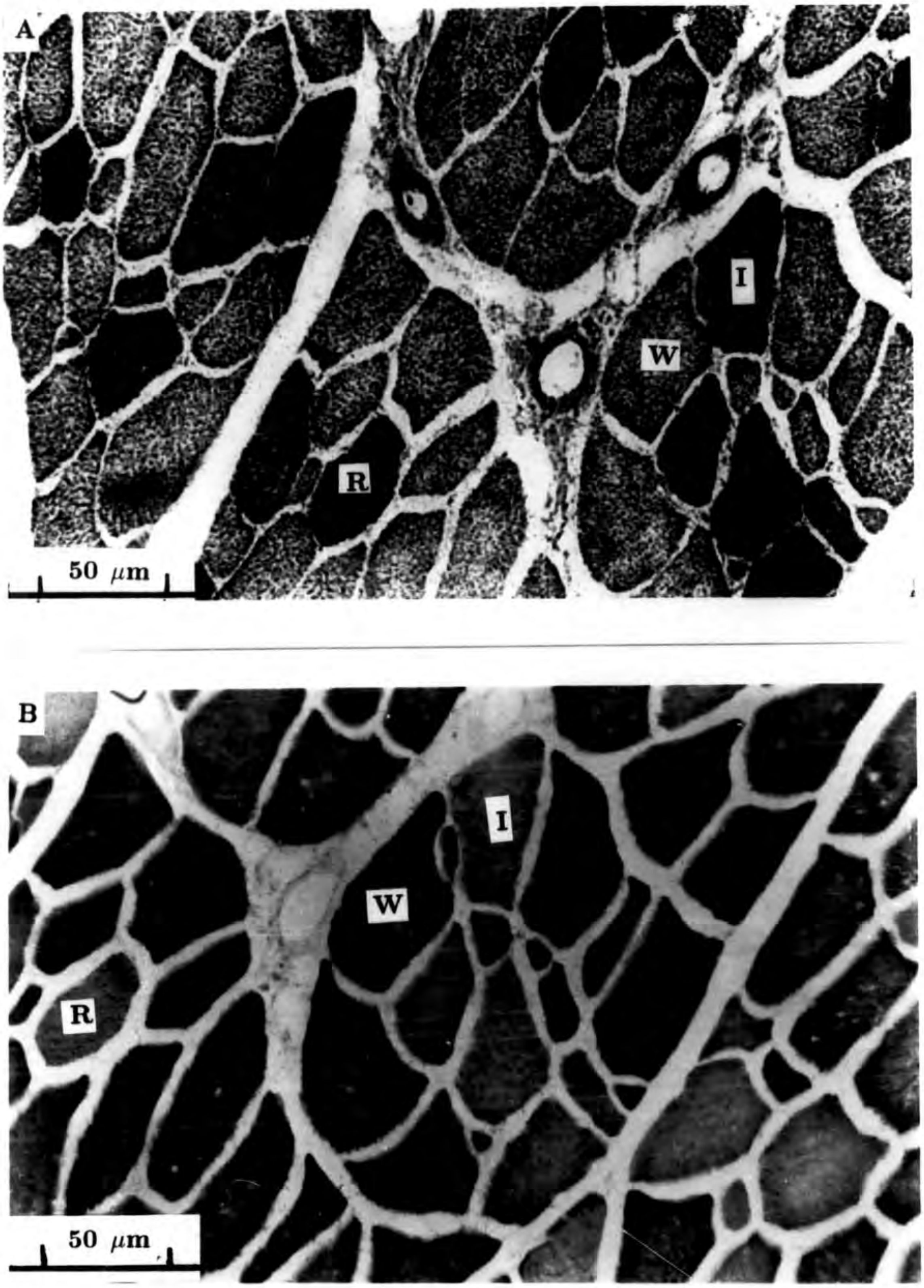


Figure 4.1 – Transverse section of the pectoralis muscle (region A) in control chicken at age 60 days showing the distribution of NADH-TR (A) and phosphorylase (B) activity. W.–White fibre (FG); I.–Intermediate fibre (FOG); and R.– Red fibre types (SO).

PLATE 4.1

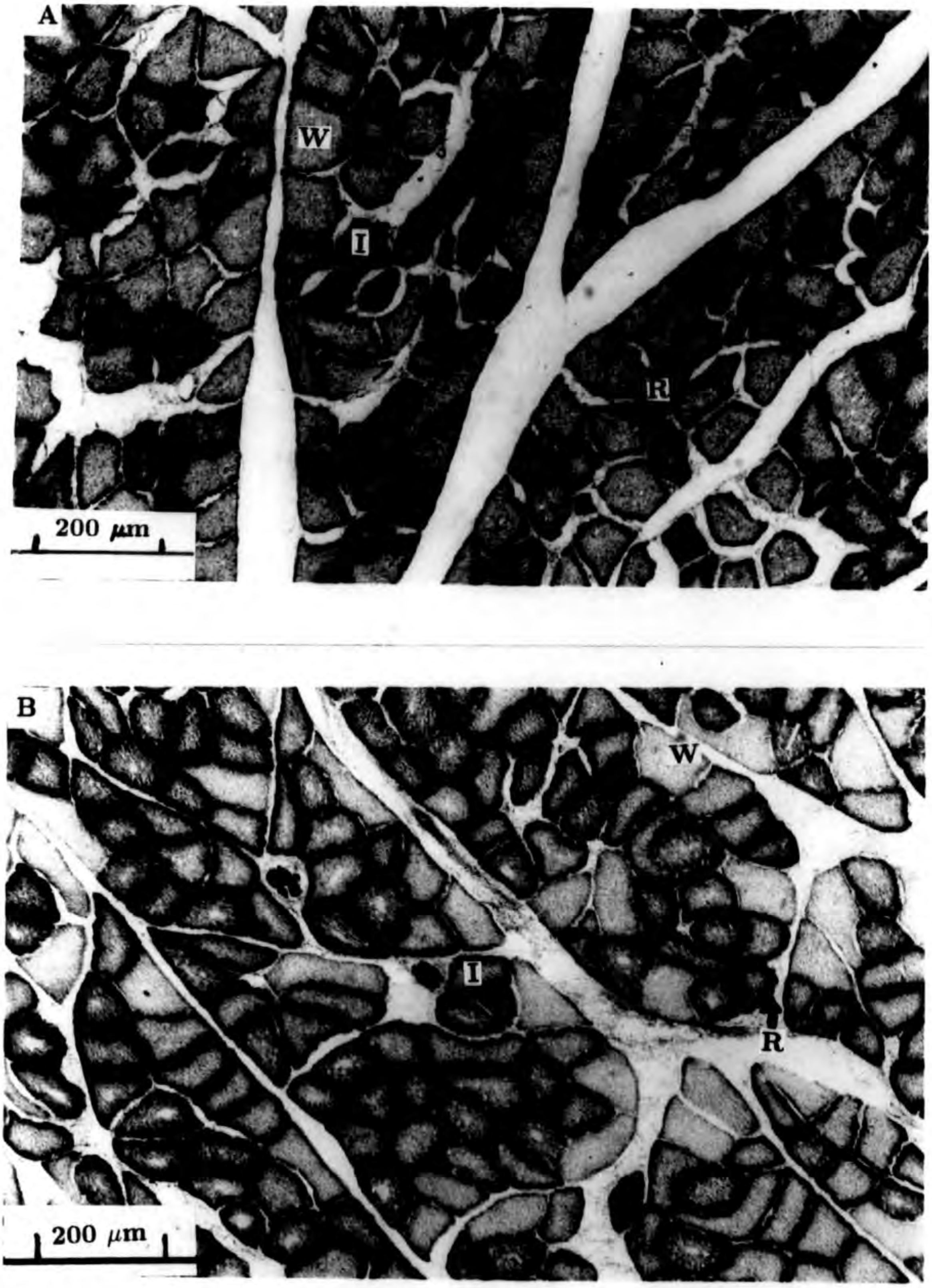


Figure 4.2 – Transverse section from the left EDL (A) and pectoralis muscle (region A) (B) in control chicken at age 100 days stained for NADH-TR activity. Abbreviation as in figure 4.1.

PLATE 4.2

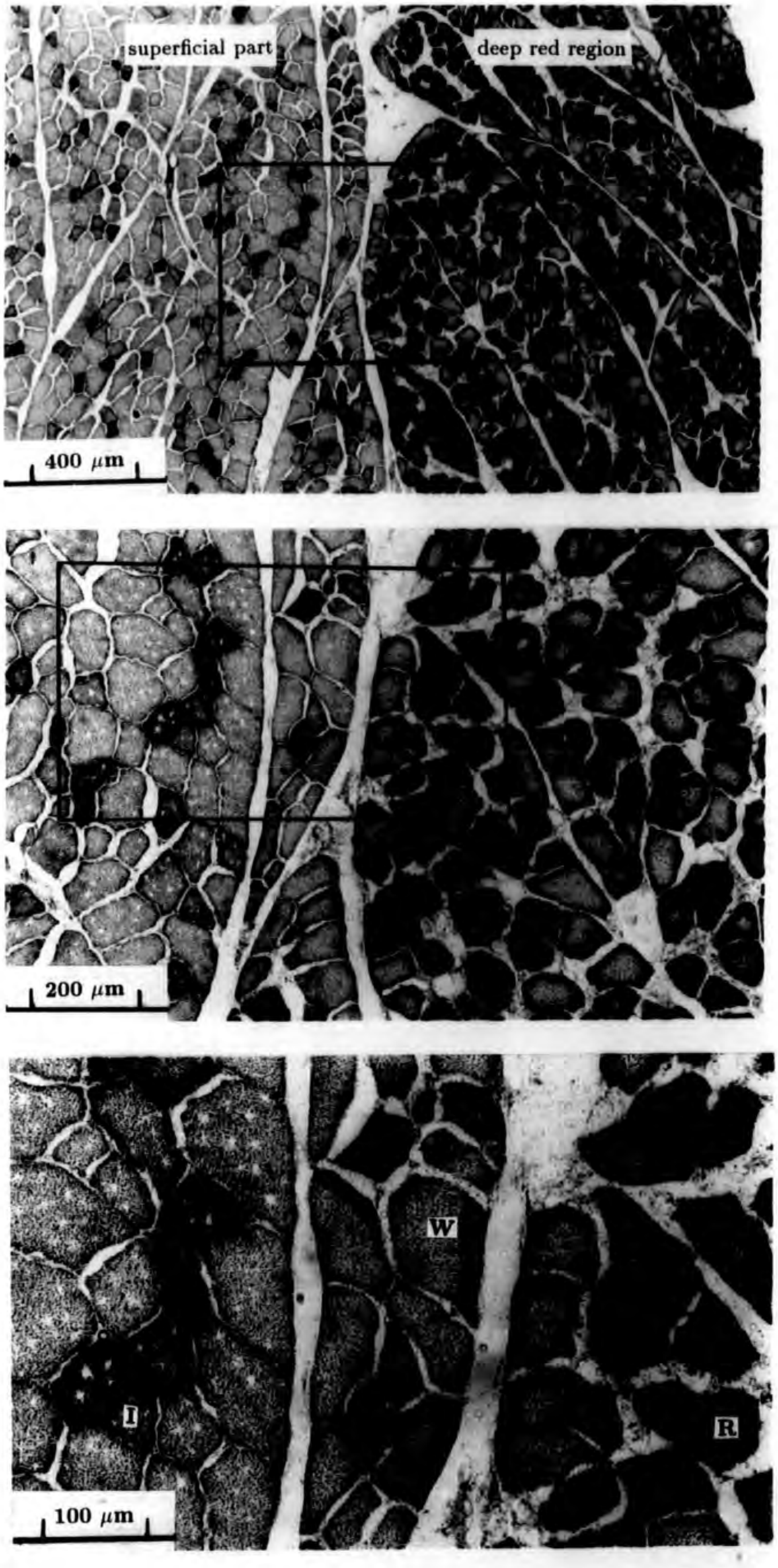
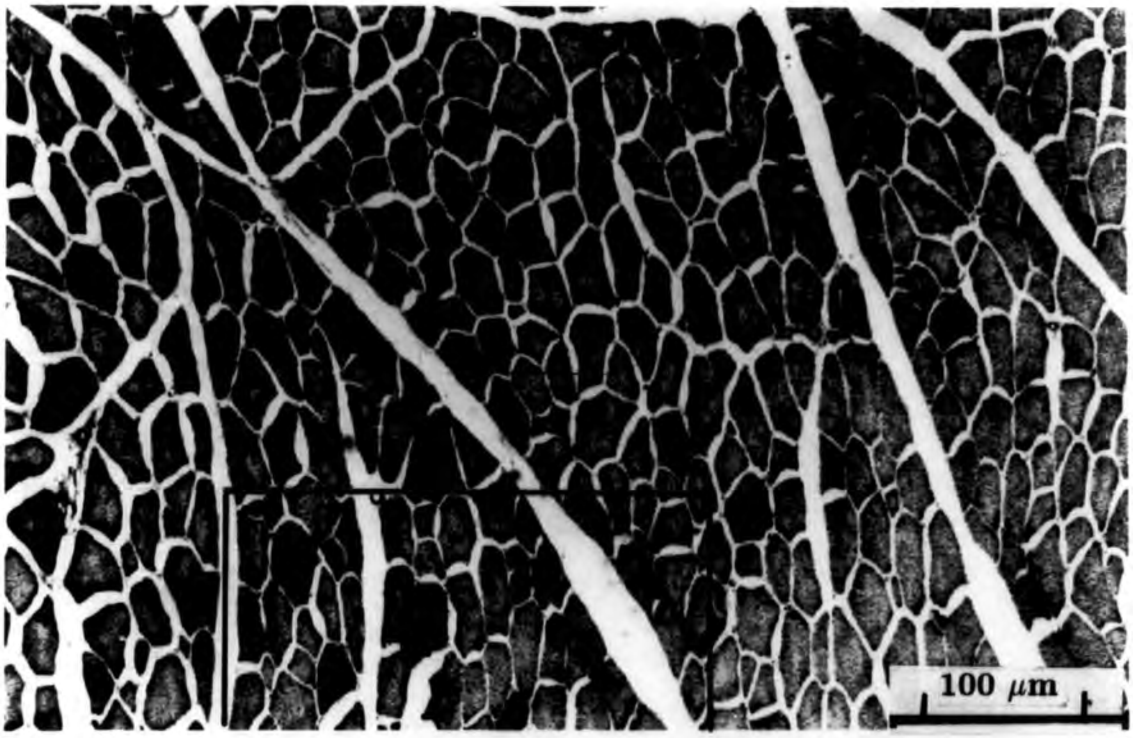


Figure 4.3 – Transverse section of the anterior region (A) of the pectoralis muscle in control chicken at age 100 days showing the distribution of NADH-TR activity in the deep distal region (red region) and superficial part of the pectoralis muscle. Abbreviation as in figure 4.1.

PLATE 4.3



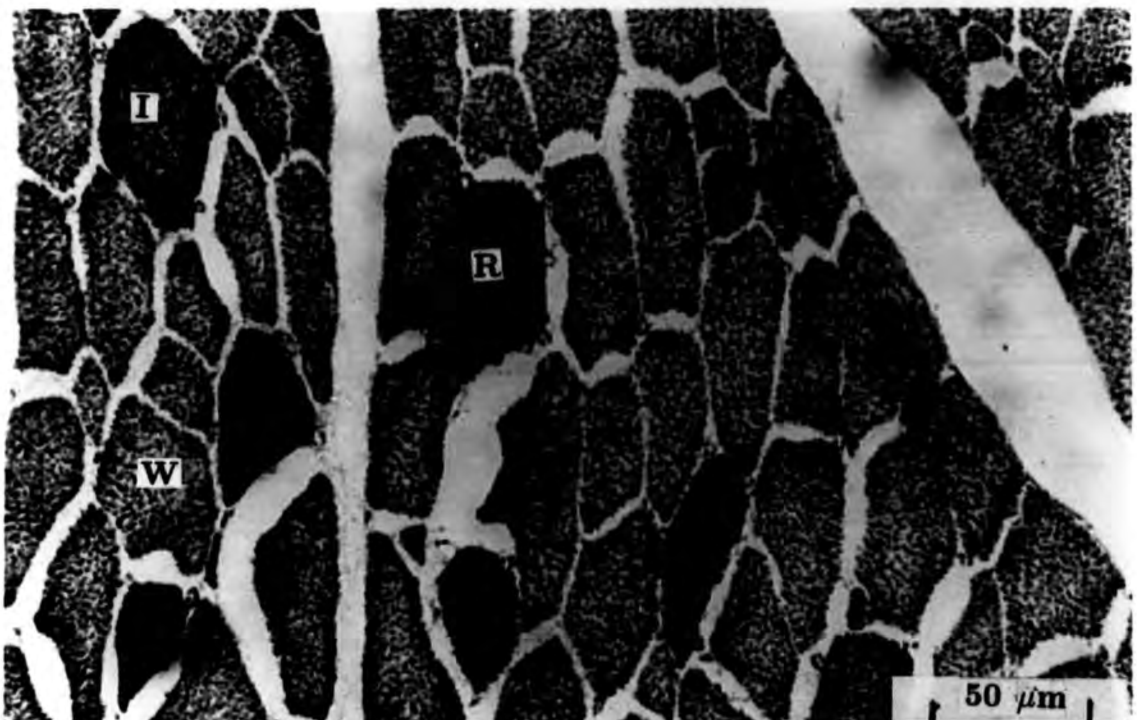


Figure 4.4 – Transverse section of the mid part (region B) of the pectoralis muscle in control chicken at age 60 days showing the distribution of NADH-TR (A) activity in the deep distal region (close to the sternum). Abbreviation as in figure 4.1.

PLATE 4·4

Table 4.1 — Average Number Per Unit Area and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Chickens

Age (days)	No. of Birds	Body Weight (gram)	Muscle Weight (gram)	Region	Fibre Type No./mm² Red(SO)	Inter.(FOG)	White(FG)	Total No./mm²	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
			R	A	34.53±6.63	76.81±7.31	858.25±41.73	969.59±40.78	20.83±0.43	24.80±0.66	28.68±0.66
			18.45±2.25	B	18.54±8.49	77.81±13.57	1046.70±42.54	1143.00±31.40	17.53±0.90	21.30±0.63	26.32±0.45
20	3	438.33±32.27	L	A	31.09±10.34	77.25±17.28	890.14±60.40	998.48±46.77	19.92±0.43	22.71±0.59	31.15±0.72
			18.44±2.14	B	22.10±5.93	69.85±15.52	1099.50±126.93	1191.40±113.39	16.97±0.43	20.92±0.59	25.38±0.54
			R	A	16.77±4.93	51.09±5.87	508.98±17.62	576.85±12.15	31.67±0.56	38.03±0.92	42.84±0.82
			45.77±1.08	B	16.59±6.05	30.28±6.00	591.67±30.39	638.55±22.27	25.06±0.47	28.94±0.67	35.65±0.53
30	3	946.67±50.85	L	A	11.01±4.24	39.41±5.50	549.97±17.88	599.97±14.04	26.51±0.51	33.03±0.58	39.82±0.56
			46.61±0.35	B	6.54 ±3.06	19.91±6.96	659.93±18.85	686.38±12.12	21.02±0.50	25.40±0.58	35.03±0.70
			R	A	12.82±4.10	33.92±8.83	367.54±27.23	476.68±20.74	36.82±0.58	43.54±1.03	47.16±1.02
			77.02±6.30	B	2.30±1.64	26.65±7.18	509.72±33.91	537.84±35.73	27.08±1.35	33.63±1.11	41.31±1.01
40	3	1620.67±83.98	L	A	12.05±4.50	40.32±11.79	396.56±27.76	448.94±25.49	33.06±0.88	41.50±0.92	46.13±0.92
			80.93±7.31	B	0.790±0.53	19.14±3.78	473.75±39.00	493.69±39.64	33.62±5.38	40.65±1.62	43.96±1.03
			R	A	8.56±1.66	24.82±4.95	258.21±10.52	291.54±9.54	36.61±1.19	53.72±1.22	58.26±1.13
			134.64±10.20	B	1.14±0.29	18.89±5.59	312.00±18.53	335.27±14.39	40.15±6.61	49.80±1.45	53.54±1.05
50	3	2363.33±16.81	L	A	7.09±1.24	28.22±4.92	263.45±6.806	303.49±8.93	37.26±1.14	52.49±1.27	56.80±1.17
			139.09±9.87	B	7.03±0.99	18.82±4.25	337.33±13.07	362.60±9.97	30.28±1.43	48.50±1.29	51.98±1.04
			R	A	7.50±2.20	14.07±2.72	226.98±7.77	248.18±9.00	45.32±1.12	52.54±1.34	65.19±1.41
			210.24±19.67	B	5.13±1.31	9.64±2.80	233.05± 9.79	246.49±11.53	44.59±2.40	57.50±1.63	69.23±1.42
60	3	3287.20±129.49	L	A	5.67±1.79	16.19±3.95	236.48±6.56	258.34±7.17	44.54±1.63	51.26±1.49	67.25±1.39
			216.63±22.50	B	7.37±1.91	8.51±1.46	279.14±16.06	294.03±16.65	37.18±1.70	51.81±1.51	59.00±1.00
			R	A	5.98±2.75	19.65±7.26	225.01±4.69	250.65±5.78	45.22±1.85	54.35±2.11	62.66±2.12
			378.85	B	2.85±1.37	11.70±3.04	211.16±21.33	228.73±17.56	60.00±3.79	75.38±2.66	74.82±2.87
100	1	4800.00	L	A	11.08±5.82	11.44±2.90	206.02±12.02	228.53±9.97	48.05±2.20	57.21±2.70	64.66±1.99
			392.11	B	0.43±0.43	17.30±3.27	263.11±10.97	280.84±12.98	42.83±5.54	61.11±3.32	66.24±1.42
			R	A	0.17±0.12	3.44±2.32	80.81± 0.54	85.40± 0.67	53.57±3.03	81.66±1.87	98.36±2.49
			464.48±9.94	B	0.61±0.23	5.91±1.31	164.16±2.58	170.68±2.07	58.00±4.45	74.65±2.34	84.14±1.75
150	2	6480.00±650.54	L	A	1.03±0.41	3.48±0.86	80.63±2.80	85.16±2.33	56.59±1.88	80.83±2.77	100.27±2.60
			494.78±18.38	B	-	4.11±1.16	160.39±4.34	164.53±4.14	-	64.49±2.19	84.08±1.78

Mean± SE is given for each measurement

Table 4.2 — Average Number Per Unit Area and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Chickens

Age (days)	No. of Birds	Body Weight (gram)	Muscle Weight (gram)	Region	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
			R	A	92.67±38.57	81.88±22.56	992.34±106.17	1166.90±81.45	20.01±0.48	22.94±0.56	26.60±0.67
			17.68±2.10	B	13.63±8.01	44.41±11.53	1095.42±55.55	1153.46±47.74	21.61±0.46	24.02±0.48	26.93±0.53
20	3	434.30±28.67	L	A	83.28±31.29	75.43±18.35	1031.90±65.42	1190.60±49.50	18.63±0.31	22.44±0.48	24.84±0.47
			18.73±2.49	B	5.23±2.62	21.31±5.44	1254.52±95.90	1281.06±96.53	15.80±0.75	22.04±0.95	22.09±0.52
			R	A	31.84±16.59	37.02±8.93	490.40±25.84	559.26±23.21	29.70±0.55	35.71±0.64	39.40±0.83
			40.13±1.59	B	10.64±8.64	19.15±7.34	647.49±37.42	677.27±45.90	27.42±1.11	33.59±0.85	33.13±0.68
30	2	958.00±52.00	L	A	22.76±9.29	43.76±9.89	497.85±23.95	564.37±27.11	29.39±0.61	38.36±0.85	39.25±0.94
			42.61±2.71	B	6.89±2.70	26.04±4.24	656.71±14.77	689.63±10.76	30.30±2.17	34.88±1.02	35.54±0.69
			R	A	29.44±10.96	47.75±12.41	344.06±28.737	421.26±14.14	36.83±0.80	44.72±0.97	50.56±1.10
			71.82±12.34	B	1.34±0.68	17.81±5.54	517.15±52.63	536.30±48.83	33.40±1.90	37.96±1.62	41.27±0.98
40	3	1414.33±132.46	L	A	20.69±6.56	33.58±7.42	377.01±22.91	431.28±17.24	35.29±1.11	42.48±0.82	43.80±0.93
			77.52±15.84	B	3.11±1.16	12.98±3.72	505.27±28.56	521.36±26.48	28.61±1.42	41.74±1.11	44.07±1.02
			R	A	26.29±8.45	23.49±4.70	254.25±10.81	304.03±6.25	47.15±0.68	53.16±0.74	63.95±1.15
			149.18±8.17	B	-	8.07±2.48	339.19±9.69	347.30±9.40	-	54.78±1.21	58.42±1.17
50	3	2636.00±146.59	L	A	10.47±4.69	20.71±3.21	244.18±9.63	275.37±7.79	51.34±1.21	57.84±1.13	65.69±1.09
			158.06±6.53	B	-	11.58±3.29	340.88±12.78	352.51±11.29	-	52.94±1.62	55.08±0.94
			R	A	14.84±4.18	17.07±3.00	190.69±5.55	222.60±4.32	54.04±8.14	57.91±0.84	72.14±1.33
			211.69±8.64	B	0.38±0.11	2.65±0.52	240.23±6.33	243.25±6.18	47.43±2.97	61.80±2.70	71.41±1.39
60	3	3360.00±151.85	L	A	9.33±3.45	18.99±4.86	178.70±5.94	207.02±6.80	51.03±0.93	60.69±1.84	77.56±1.73
			220.32±7.63	B	0.32±0.10	3.99±0.65	220.50±7.30	224.81±7.25	50.80±3.47	57.68±2.69	66.47±1.32
			R	A	2.20±0.55	13.49±2.91	108.11±3.70	123.80±3.70	56.91±1.66	67.28±1.17	92.98±1.75
			374.12±20.08	B	0.46±0.14	3.85±1.07	154.49±5.78	158.81±5.54	57.41±2.70	72.30±2.92	84.65±1.59
100	3	5783.33±235.11	L	A	3.35±0.89	15.23±3.38	102.47±3.54	121.05±2.24	61.88±1.16	74.36±1.58	96.15±1.53
			404.64±13.67	B	1.50±0.51	2.05±0.27	157.11±5.97	167.66±4.87	49.97±2.05	69.93±2.04	78.94±2.72
			R	A	4.08±2.76	15.46±8.09	82.81±7.87	102.35±5.03	62.90±1.02	73.41±1.55	103.80±3.43
			492.22	B	0.81±0.18	2.43±1.06	143.11±4.25	145.62±3.64	67.79±3.38	74.07±2.62	88.91±2.11
150	1	7150.00	L	A	5.85±3.53	10.68±5.34	91.93±5.65	108.46±4.08	75.15±1.74	76.29±1.64	111.25±2.40
			521.25	B	-	1.03±0.49	143.92±3.58	144.98±3.68	-	75.51±2.37	85.29±2.22

Mean± SE is given to each measurement

comprises less than 1% of the total mass of the adult pectoralis muscle (Gauthier and Lowey 1977; Matsuda *et al.,* 1983). As a result of this difference between the superficial and deep part, fibre counts were taken from each microscopic field starting from the deep red side of the pectoralis (close to the sternum) moving site by site through the muscle belly until the last field at the superficial side. The mean number of each type of fibre per square millimeter (fibre-type number) was calculated for each microscopic field, then the average was calculated from all microscopic fields by using the computer program (1) in appendix A. The results are presented for each individual bird in appendix C tables. The overall-mean of the fibre type number of each age group was calculated and presented with standard error in tables 4.1 and 4.2 for control and selected chickens respectively.

Fibre diameter was measured from the first 3-4 microscopic fields starting from the deep red side in order to measure all the three fibre types in that area because SO fibres do not appear (or very rarely) in the later microscopic fields towards the superficial side. For each bird the mean diameter of each fibre type (the 'fibre-type diameter') was calculated in a similar way to mean fibre-type number by using the computer program (2) in appendix A. The results are presented in appendix C. Also the overall mean of the fibre-type diameter for each age group was calculated by using the computer program (3) in appendix A and the results presented in tables 4.1 and 4.2 for the control and selected chickens respectively.

The proportion of each fibre type. i.e. the number of each fibre type divided by the total fibre number per square millimeter was also calculated and the overall means with standard error are presented in tables 4.4 and 4.8 for the control and selected chickens respectively.

Student's *t*-test was used to compare the fibre numbers and diameters between

Table 4.3 — Result of the *t*-test on the Average Number and Diameter Fibre Types in Regions A and B of the Pectoralis Muscle in Control Chickens

Age (days)	No. of Birds	Side and Region	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
20	3	RA/RB	2.259^{*a}	N.S.	2.711^{*b}	N.S.	3.687^{***a}	3.803^{***a}	3.041^{**a}
		LA/LB	N.S.	N.S.	N.S.	N.S.	4.826^{***a}	2.148^{*a}	6.513^{***a}
30	3	RA/RB	N.S.	2.128^{*b}	2.480^{*b}	2.625^{*b}	8.780^{***a}	7.008^{***a}	7.201^{***a}
		LA/LB	N.S.	2.195^{*b}	4.046^{***b}	4.260^{***b}	6.543^{***a}	7.771^{***a}	5.364^{***a}
40	3	RA/RB	2.378^{*a}	N.S.	3.270^{**b}	N.S.	7.131^{***a}	6.462^{***a}	4.081^{***a}
		LA/LB	2.486^{*a}	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
50	3	RA/RB	3.907^{***a}	N.S.	2.660^{*b}	2.625^{*b}	N.S.	2.075^{*a}	3.027^{**a}
		LA/LB	N.S.	N.S.	5.401^{***b}	4.386^{***b}	3.819^{***a}	2.084^{*a}	2.971^{**a}
60	3	RA/RB	N.S.	N.S.	N.S.	N.S.	N.S.	2.350^{*b}	1.990^{*b}
		LA/LB	N.S.	N.S.	2.618^{*b}	2.090^{*b}	3.095^{**a}	N.S.	5.151^{***a}
100	1	RA/RB	N.S.	N.S.	N.S.	N.S.	3.947^{***b}	5.778^{***b}	3.317^{**b}
		LA/LB	N.S.	N.S.	3.242^{**b}	3.220^{**b}	N.S.	N.S.	N.S.
150	2	RA/RB	N.S.	N.S.	38.649^{***b}	46.201^{***b}	N.S.	3.362^{*a}	4.751^{***a}
		LA/LB	N.S.	N.S.	16.166^{***b}	18.088^{***b}	–	4.552^{***a}	5.188^{***a}

Number of asterisks indicates degree of significance of the t-test. a or b indicates the A or B region which is larger in number or diameter of the fibre type.

regions within a muscle, between the right and left within each group of the control and selected chickens, and between each region in control to its corresponding one in the selected chickens.

4.2 Region A Vs. Region B in Control Chickens

The structure of pectoralis muscle is not uniform. As mentioned above the superficial side of pectoralis muscle contains FG fibres almost exclusively, whereas

Table 4.4 — Mean Number of Muscle Fibres by Type as Percentages to the Total Numbers in Right and Left Side Pectoralis Muscles in Control Chickens

Region	Fibre Type	Side	20	30	40	50	60	100†	150
A	White	R	88.40 ± 0.91	88.15 ± 1.14	90.78 ± 2.33	88.66 ± 4.39	90.92 ± 0.59	89.77	94.64 ± 1.37
		L	89.50 ± 1.76	91.82 ± 1.53	88.33 ± 0.01	88.87 ± 3.33	91.52 ± 0.81	90.15	94.66 ± 0.70
	Intermediate	R	8.02 ± 1.65	8.94 ± 1.34	6.70 ± 1.84	8.43 ± 3.40	5.16 ± 1.40	7.84	4.01 ± 2.69
		L	7.58 ± 0.99	6.42 ± 1.56	8.65 ± 2.29	8.76 ± 3.32	6.27 ± 0.23	5.01	4.12 ± 1.12
	Red	R	3.58 ± 0.82	2.91 ± 0.48	2.51 ± 0.75	2.92 ± 1.01	3.92 ± 1.78	2.39	0.20 ± 0.14
		L	2.93 ± 0.81	1.76 ± 0.74	2.99 ± 2.33	2.41 ± 0.06	2.22 ± 0.59	4.85	1.22 ± 0.43
B	White	R	91.91 ± 1.76	91.85 ± 2.88	92.90 ± 2.57	93.01 ± 4.32	94.32 ± 1.39	92.32	96.40 ± 1.05
		L	91.48 ± 2.98	95.32 ± 2.73	95.90 ± 0.52	92.80 ± 2.53	94.46 ± 1.29	93.69	97.41 ± 0.53
	Intermediate	R	6.69 ± 0.80	5.18 ± 1.58	4.36 ± 1.38	5.72 ± 3.82	3.50 ± 1.18	5.12	3.28 ± 0.79
		L	6.51 ± 2.26	3.40 ± 2.56	3.96 ± 0.32	5.26 ± 2.22	2.82 ± 0.41	6.16	2.55 ± 0.53
	Red	R	1.40 ± 1.09	2.97 ± 1.43	0.85 ± 0.71	1.27 ± 0.55	2.18 ± 0.98	1.25	–
		L	2.00 ± 0.88	1.27 ± 0.76	0.19 ± 0.19	1.95 ± 0.32	2.58 ± 1.09	0.15	–

Mean± SE is given for each measurement.

†One bird only.

the deepest side (close to the sternum) contains more SO fibres, as shown in figure 4.3, plate 4.3. Also, the two regions A and B differed in fibre-type number per square millimeter and in fibre diameter (see figures 4.3 and 4.4, plates 4.3 and 4.4).

4.2.1 Number of Muscle Fibres Per Square Millimeter

4.2.1.1 Total Fibre Number

Data of the total numbers of muscle fibres per square millimeter are plotted in figures 4.1 and 4.2 for regions A and B respectively in the control chickens. Student's *t*-test revealed that the total fibre number in region B was significantly larger than in region A at both sides of pectoralis muscle, as shown in table 4.3 and figures 4.5 and 4.6.

4.2.1.2 White Fibres (FG)

Figures 4.7 and 4.8 show results for the white-fibre in regions A and B of the right and left pectoralis muscle in control chickens. Student's *t*-test showed that white-fibre number was significantly larger in region B than in region A.

White-fibre percentile number to the total number of fibres in region B was higher than region A. However, there was no significant difference between the two regions in control chickens as shown in table 4.4.

4.2.1.3 Intermediate Fibres (FOG)

Data of intermediate-fibre type number in regions A and B were plotted in figures 4.9 and 4.10 respectively for control chickens. Intermediate-fibre number in region A was not significantly different from region B in the control chickens with exception of age 30 when it was significantly larger than in region B.

FIGURE 4.5 – TOTAL NUMBER OF THE RIGHT PECTORALIS MUSCLE FIBRES IN CONTROL CHICKENS (REGION A VS. B)

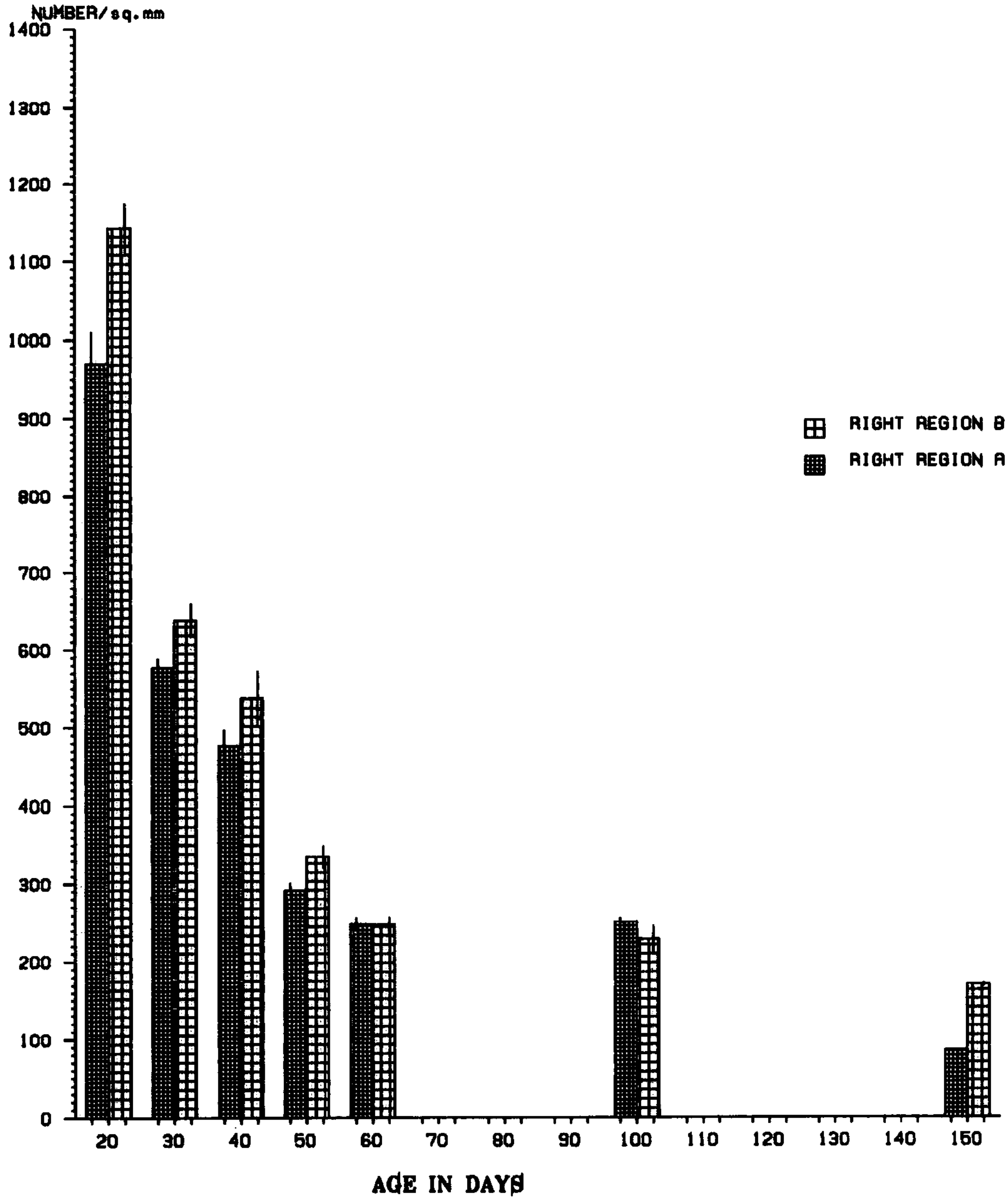
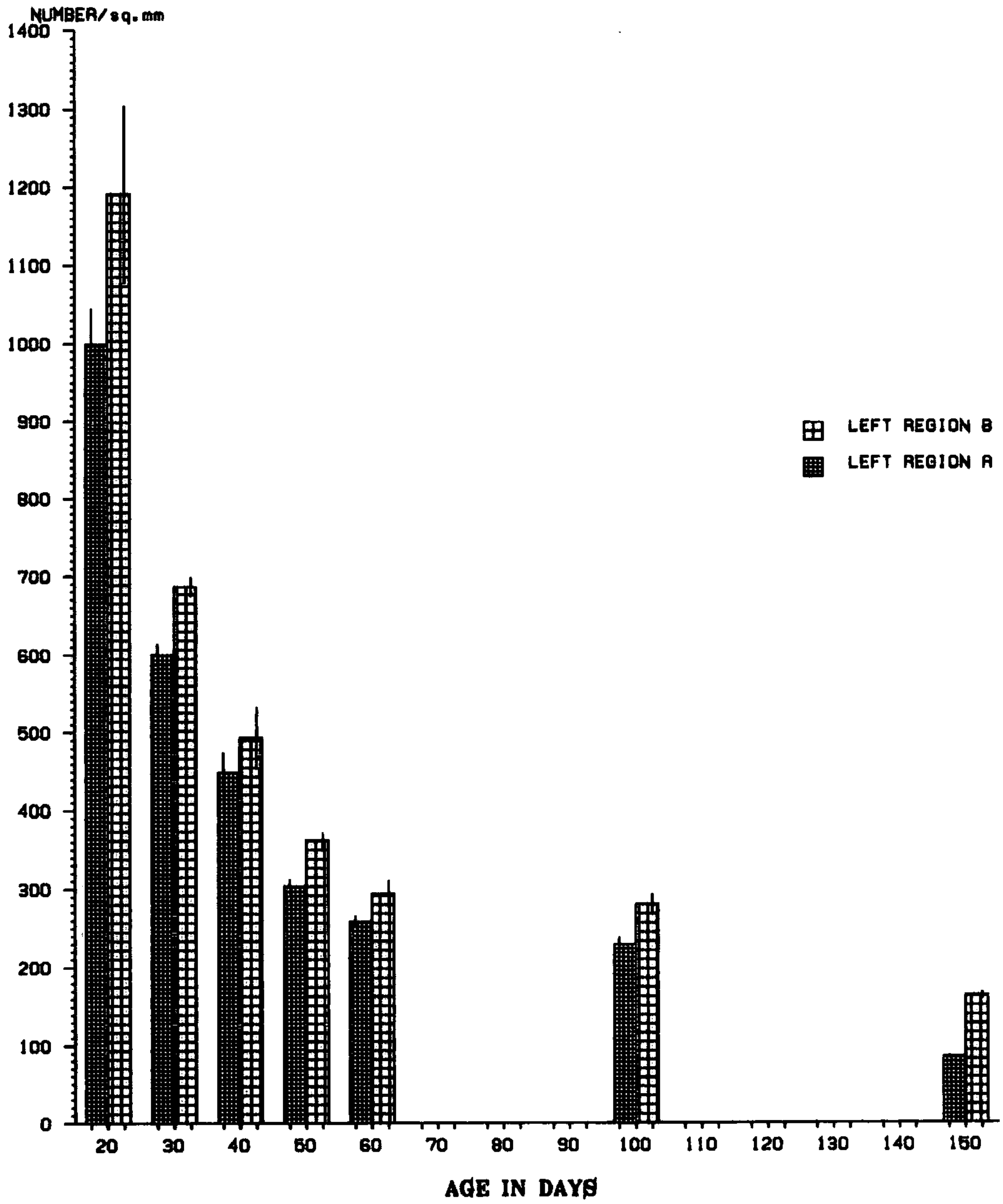


FIGURE 4.6 – TOTAL NUMBER OF THE LEFT PECTORALIS MUSCLE FIBRES IN CONTROL CHICKENS (REGION A VS. B)



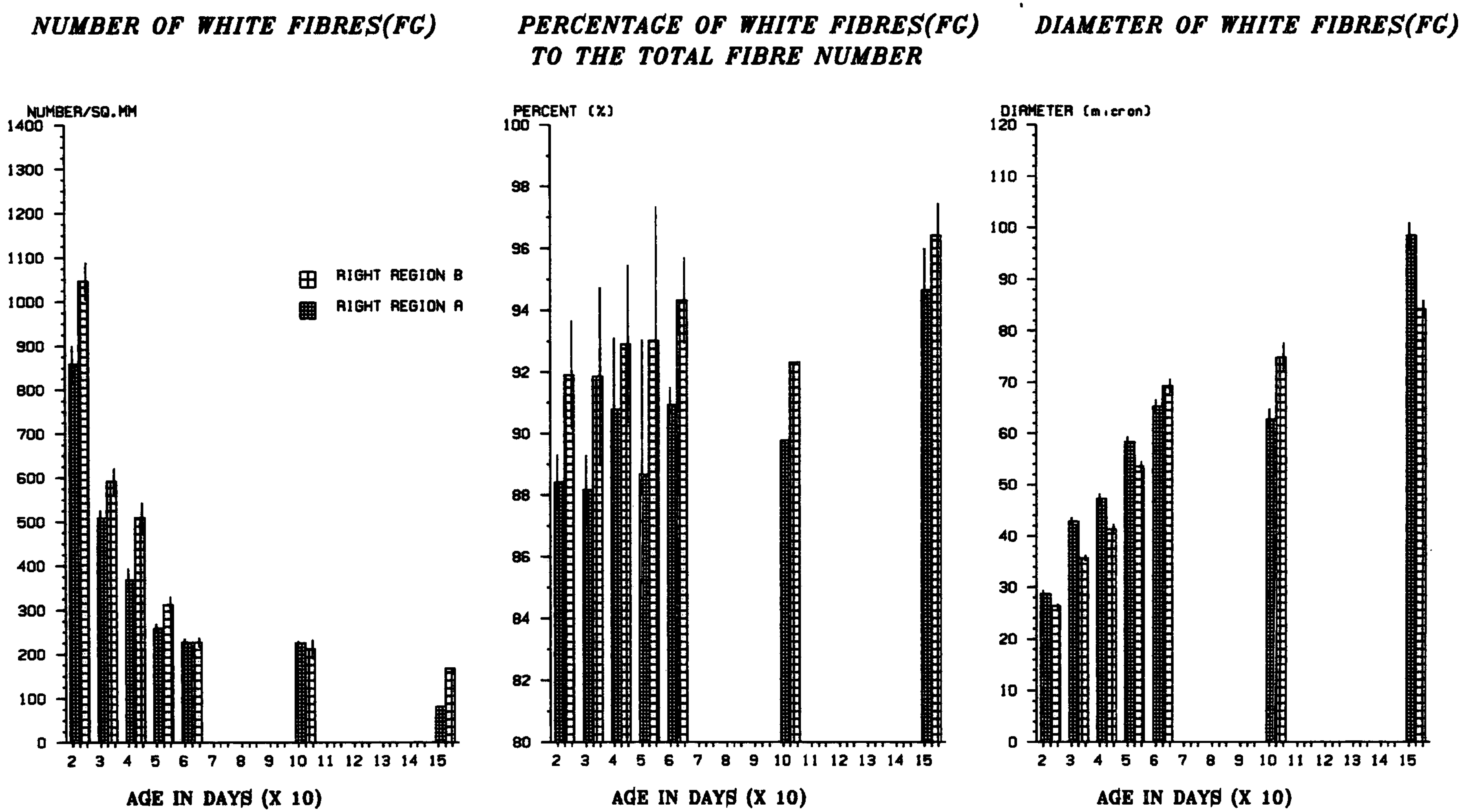


FIGURE 4.7 – WHITE FIBRES(FG) IN THE RIGHT PECTORALIS MUSCLE IN CONTRIL CHICKENS (REGION A VS. B)

(OVERALL MEAN WITH STANDARD ERROR)

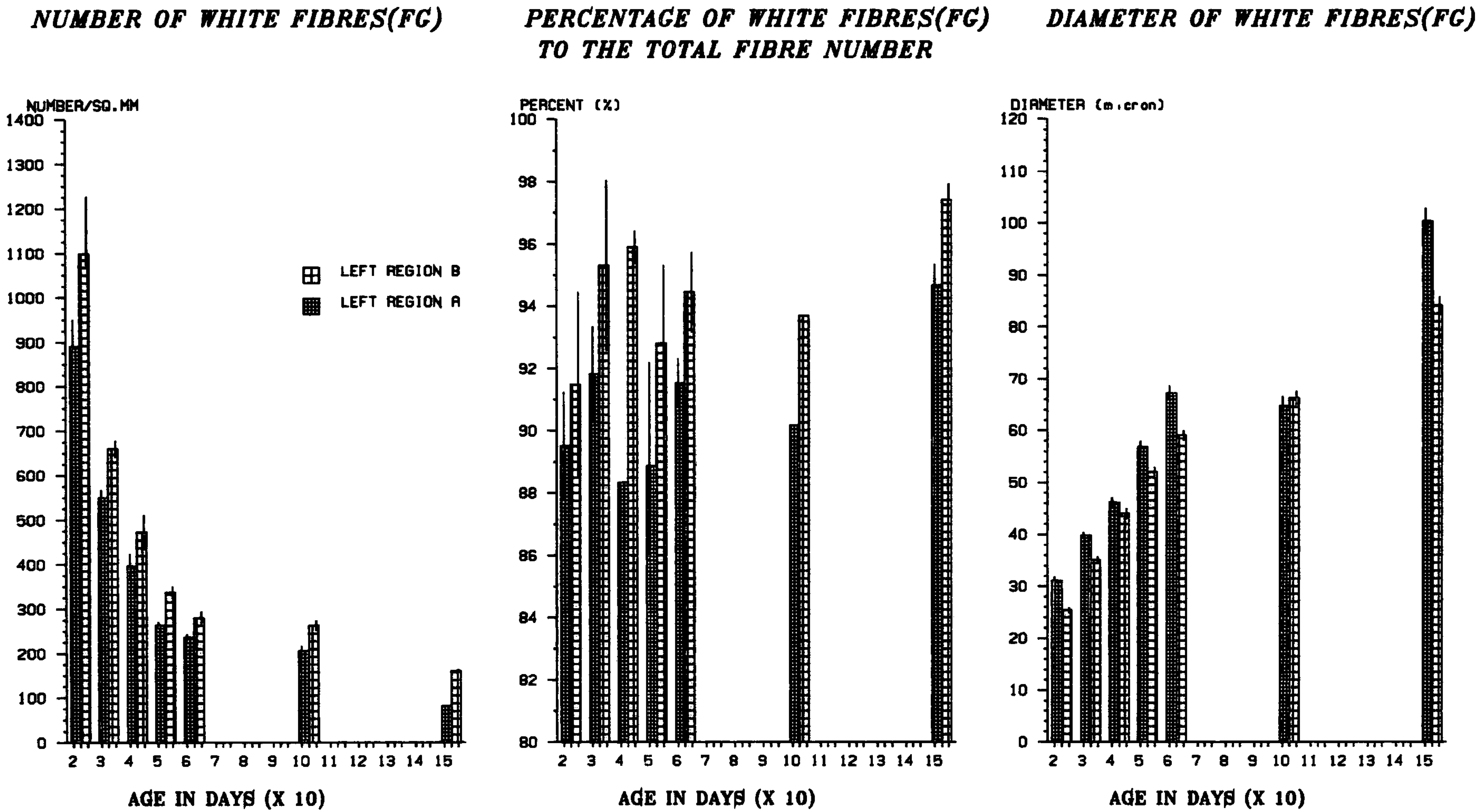


FIGURE 4.8 – WHITE FIBRES (FG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL CHICKENS (REGION A VS. B)
(OVERALL MEAN WITH STANDARD ERROR)

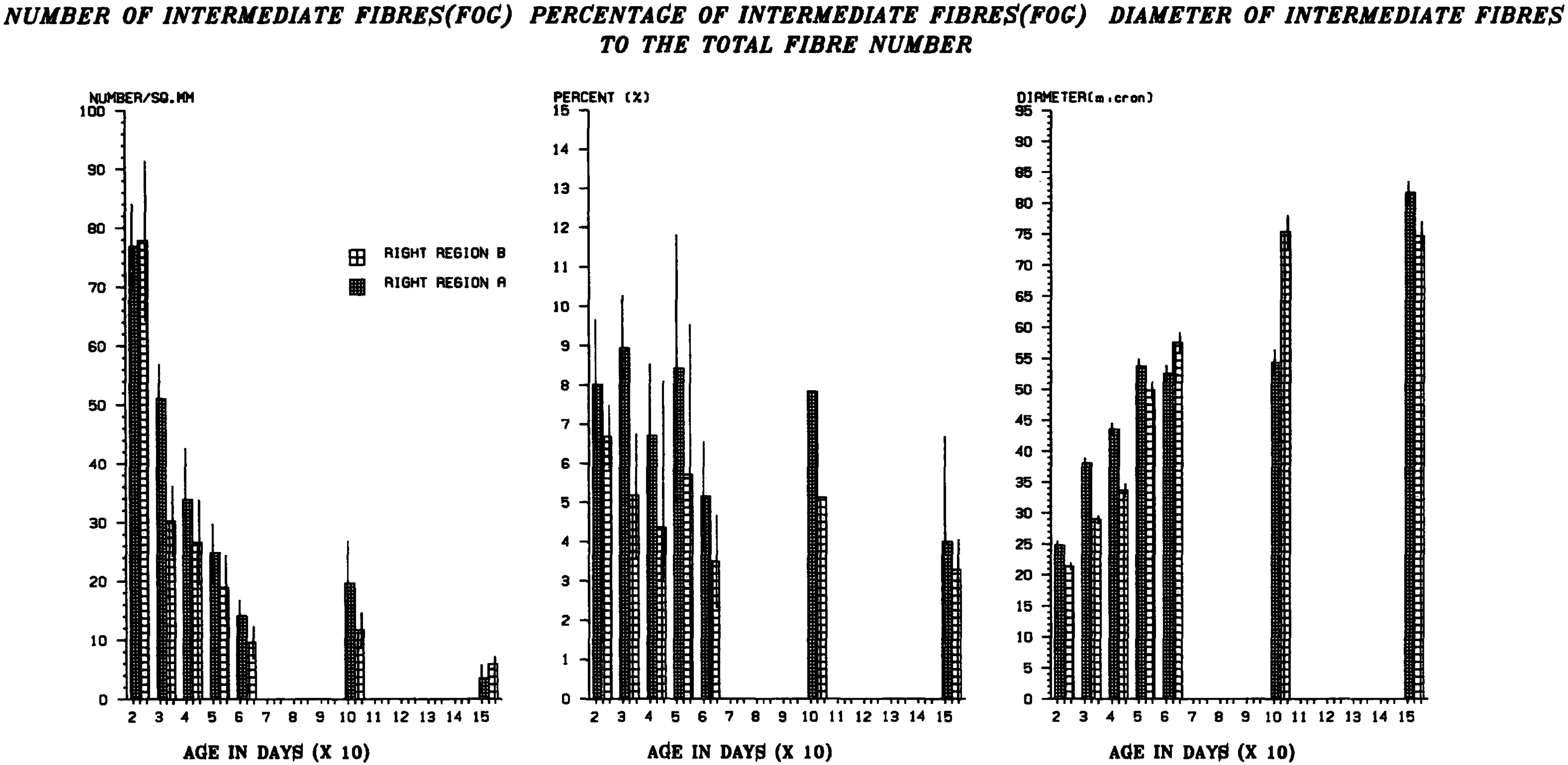


FIGURE 4.9 – INTERNEDIATE FIBRES (FOG) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL CHICKENS (REGION A VS. B)

(OVERALL MEAN AND STANDARD ERROR)

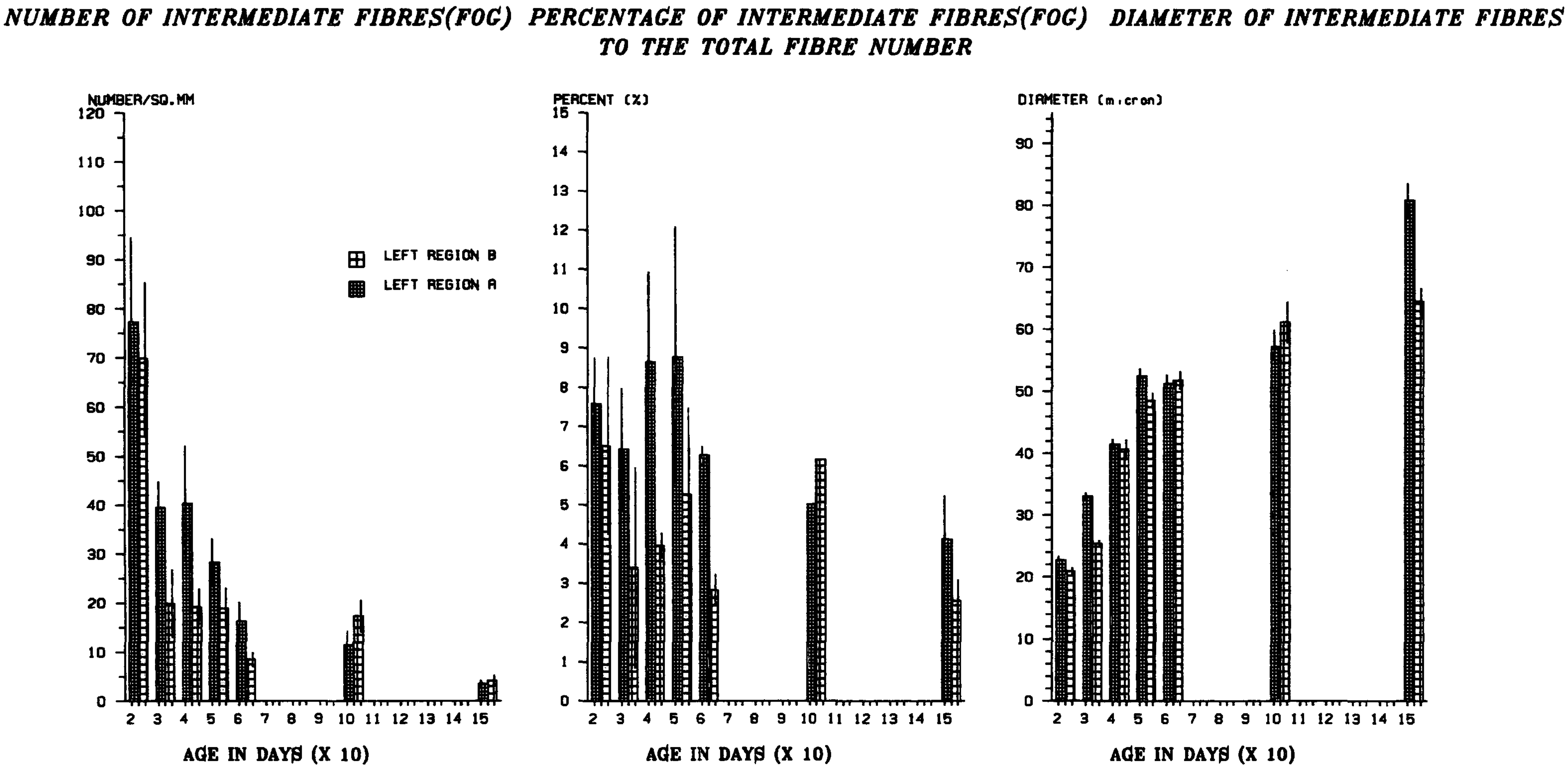


FIGURE 4.10 – INTERMEDIATE FIBRES (FOG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL CHICKENS (REGION A VS. B)

(OVERALL MEAN WITH STANDARD ERROR)

The percentage of intermediate-fibre to the total number of fibres in region A was higher than in region B at both sides of the control chickens. However, there was no significant difference between the two regions, A and B (table 4.4).

4.2.1.4 Red Fibres (SO)

The data on the number of red-fibre type per square millimeter are plotted in figures 4.11 and 4.12 respectively for regions A and B of control chickens. Student's *t*-test showed that red-fibre number was significantly larger in region A than region B over age in control chickens (see table 4.3).

Percentile red-fibre number to the total number of fibres in regions A and B was not significantly different in control chickens which might be due to the large standard deviation of the red fibres percentage in regions A and B (table 4.4).

4.2.2 Diameter of Muscle Fibres

The overall means of the fibre-type diameter at different ages in control chickens are presented in table 4.1. Student's *t*-test was carried out between the diameter of fibre type in regions A and B within a muscle, the result is presented in table 4.3.

4.2.2.1 White Fibres (FG)

Data from regions A and B are plotted in figures 4.7 and 4.8 respectively for control chickens. There were significant differences between the two regions within the pectoralis muscle in both control and selected chickens. Region A contains a very significantly larger diameter of white-fibre than region B as shown in table 4.3. This explains the above result (section 4.2.1.1) of having a significant smaller total fibre number per square millimeter in region A rather than in region B, since

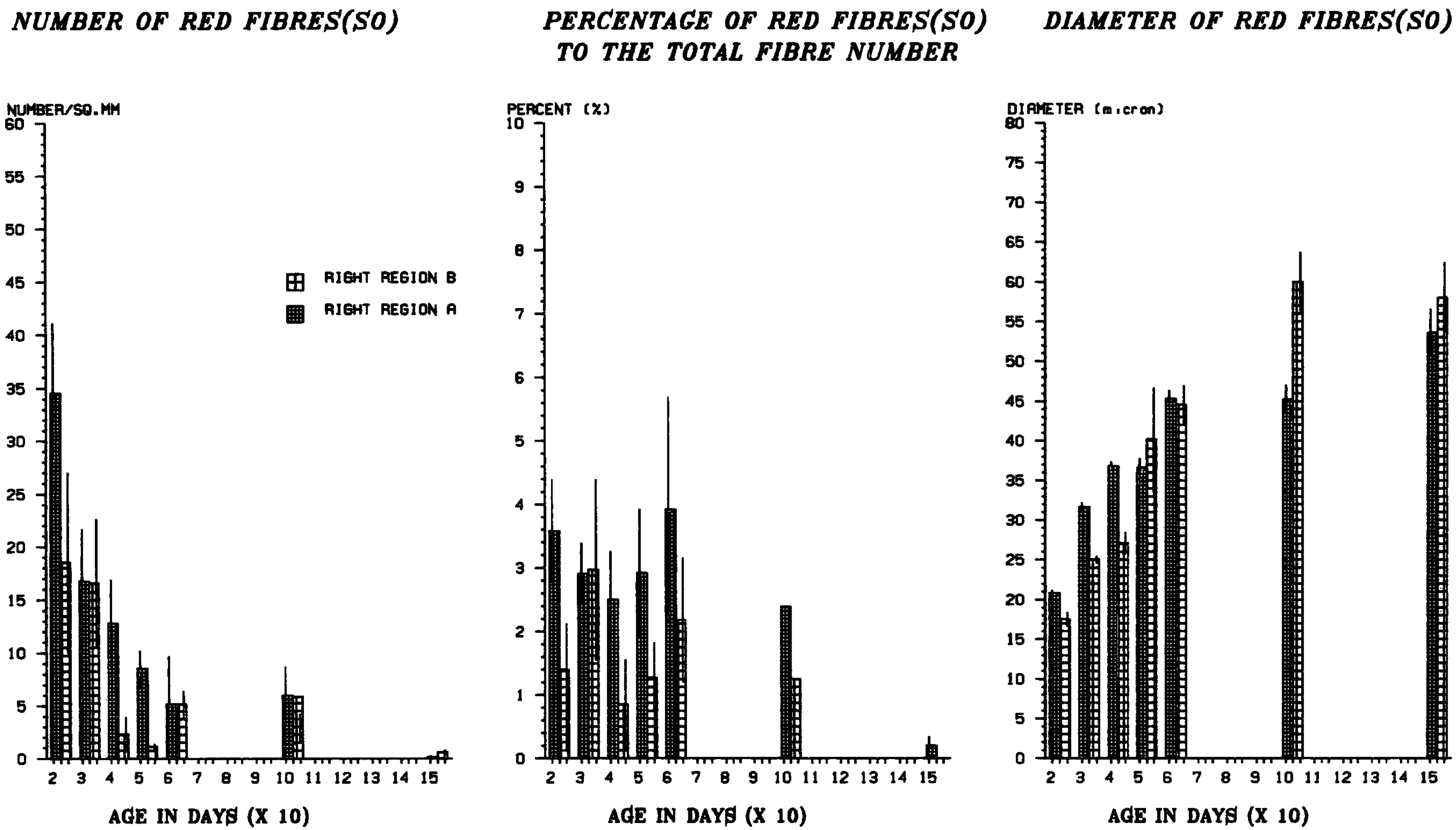


FIGURE 4.11 – RED FIBRES (SO) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL CHICKENS (REGION A VS. B)
(OVERALL MEAN WITH STANDARD ERROR)

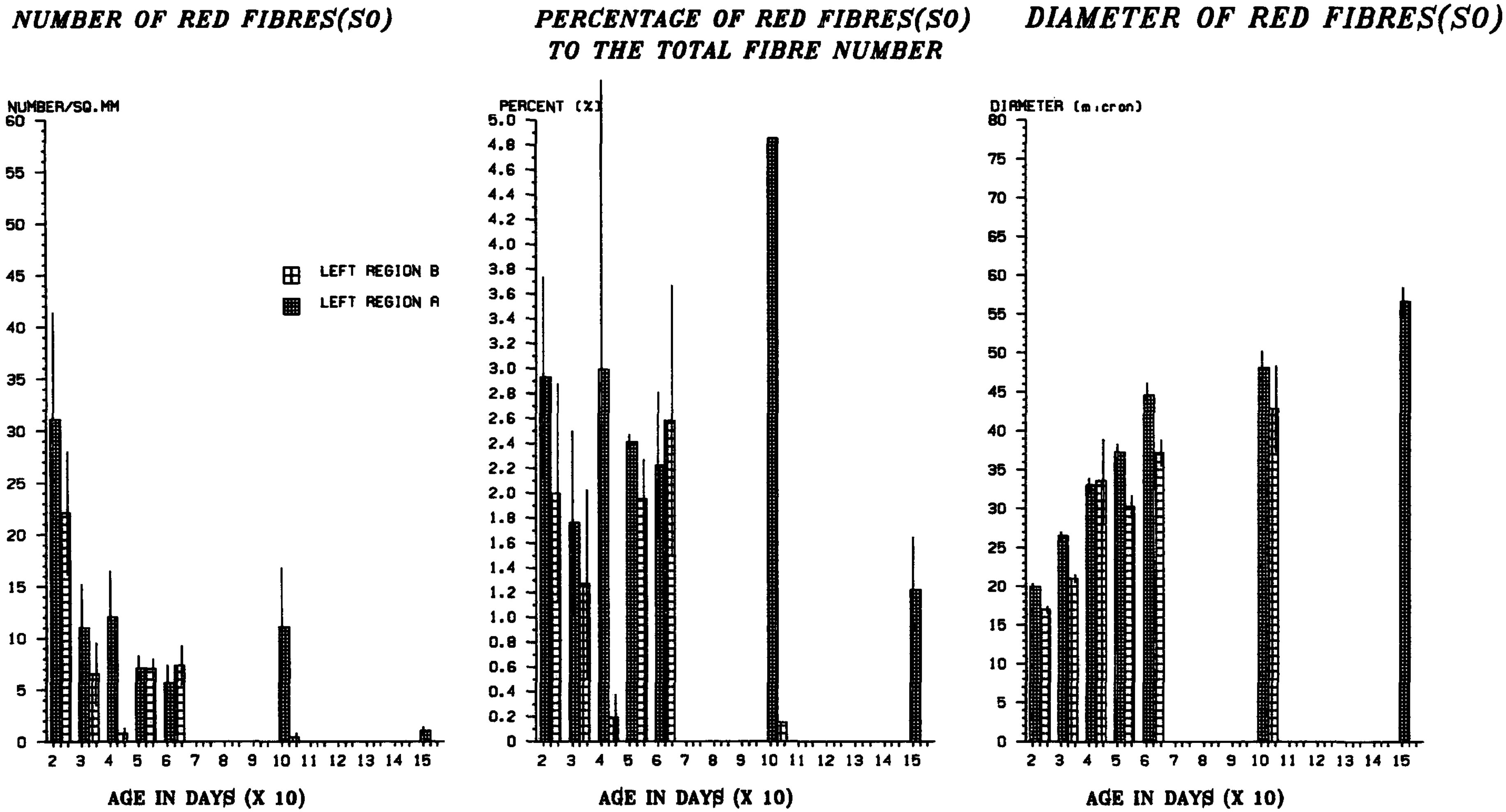


FIGURE 4.12 – RED FIBRES (SO) IN THE LEFT PECTORALIS MUSCLE IN CONTROL CHICKENS (REGION A VS. B)
(OVERALL MEAN WITH STANDARD ERROR)

the majority of fibres are white fibres.

4.2.2.2 Intermediate Fibres (FOG)

The data of the diameters of intermediate-fibres from regions A and B were plotted in figures 4.9 and 4.10 respectively for control chickens. The diameter was significantly larger in region A than in region B in the control chickens except at age 60 and 100 days where the right region B had significantly larger diameter as shown in table 4.3.

4.2.2.3 Red Fibres (SO)

The diameter of red-fibres was significantly larger in region A than in region B in control chickens as shown in figures 4.11 and 4.12.

4.3 Right Vs. Left Side of Pectoralis Muscle in Control Chickens

The numbers and diameters of fibres in the right and left pectoralis for both A and B regions in control chickens were compared using Student's t-test to reveal any difference in the structure of pectoralis muscle in both sides of the pectoralis muscle.

4.3.1 Number of Fibres Per Square Millimeter

4.3.1.1 Total Fibre Number Per Square Millimeter

- Region A

The total fibre number per square millimeter was not significantly different between the right and left side in control chickens, as shown in table 4.5. Figure 4.13 shows that control chickens had no significant differences in the total fibre

Table 4.5 — Result of t-test Between RA Vs. LA and RB Vs. LB of the Average Number and Diameter of Fibres in Pectoralis Muscle in Control Chickens

Age (days)	No. of Birds	Side and Region	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibres Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
20	3	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	2.364^{*R}	2.528^{*L}
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
30	3	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	4.618^{***R}	3.004^{**R}
		RB/LB	N.S.	N.S.	N.S.	N.S.	5.429^{***L}	3.797^{***R}	N.S.
40	3	RA/LA	N.S.	N.S.	N.S.	N.S.	3.615^{***R}	N.S.	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	3.703^{***L}	N.S.
50	3	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		RB/LB	5.719^{***L}	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
60	3	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		RB/LB	N.S.	N.S.	2.765^{**L}	2.421^{*L}	2.591^{*R}	2.560^{*R}	5.865^{***R}
100	1	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
150	2	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	3.147^{**R}	N.S.

Number of asterisks indicates degree of significance of the t-test. R or L indicates the right or left side which is significantly larger in number or diameter of the fibre type.

number per square millimeter between the right and left side of region A.

- Region B

In a similar way, Student's t-test revealed no significant differences between the right and left side in control chickens as shown in figure 4.14, except at age 60 days when the control and selected chickens had significantly larger total fibre number in the left side.

FIGURE 4.13 – TOTAL NUMBER OF MUSCLE FIBRES IN CONTROL CHICKENS (REGION A)

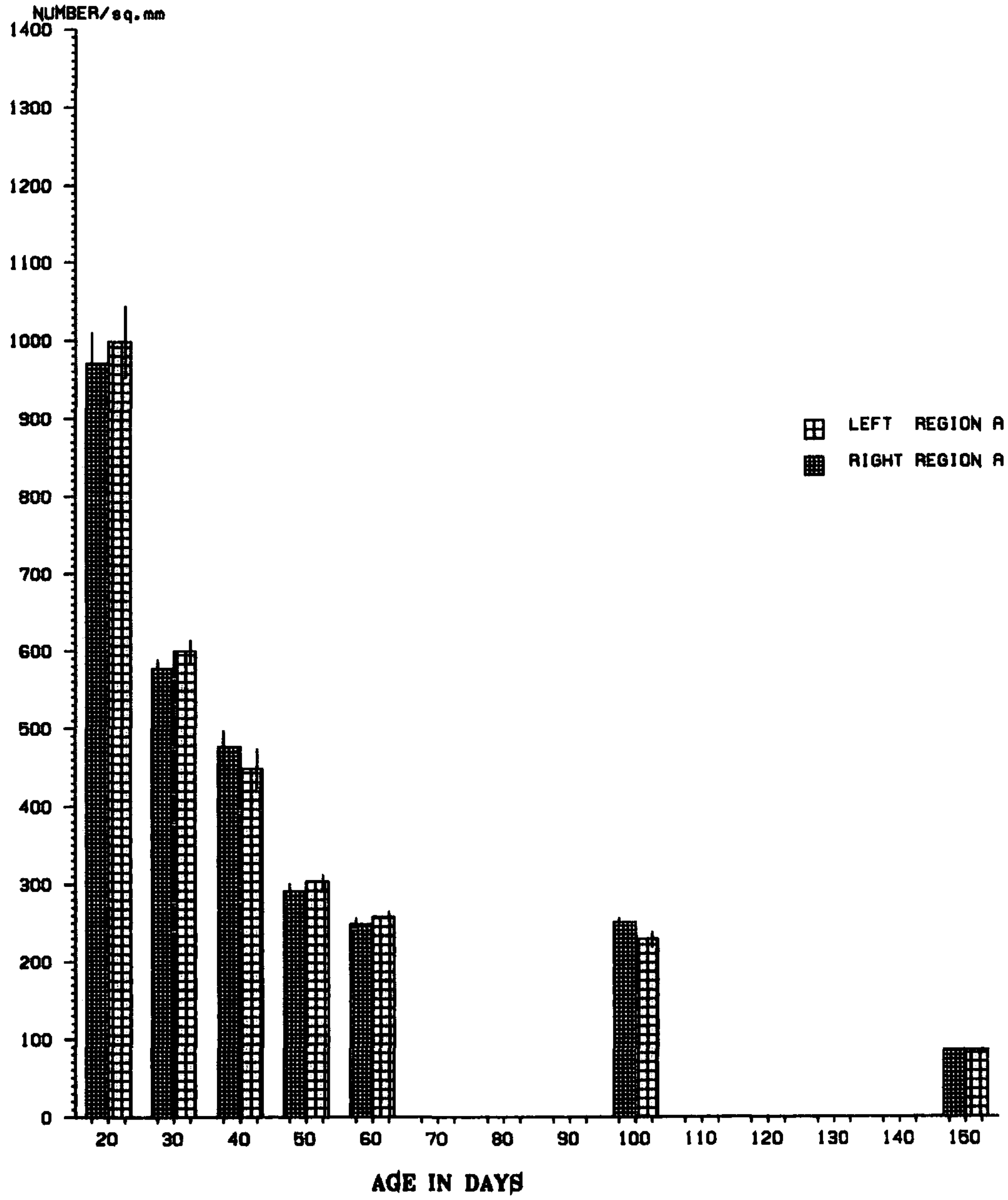
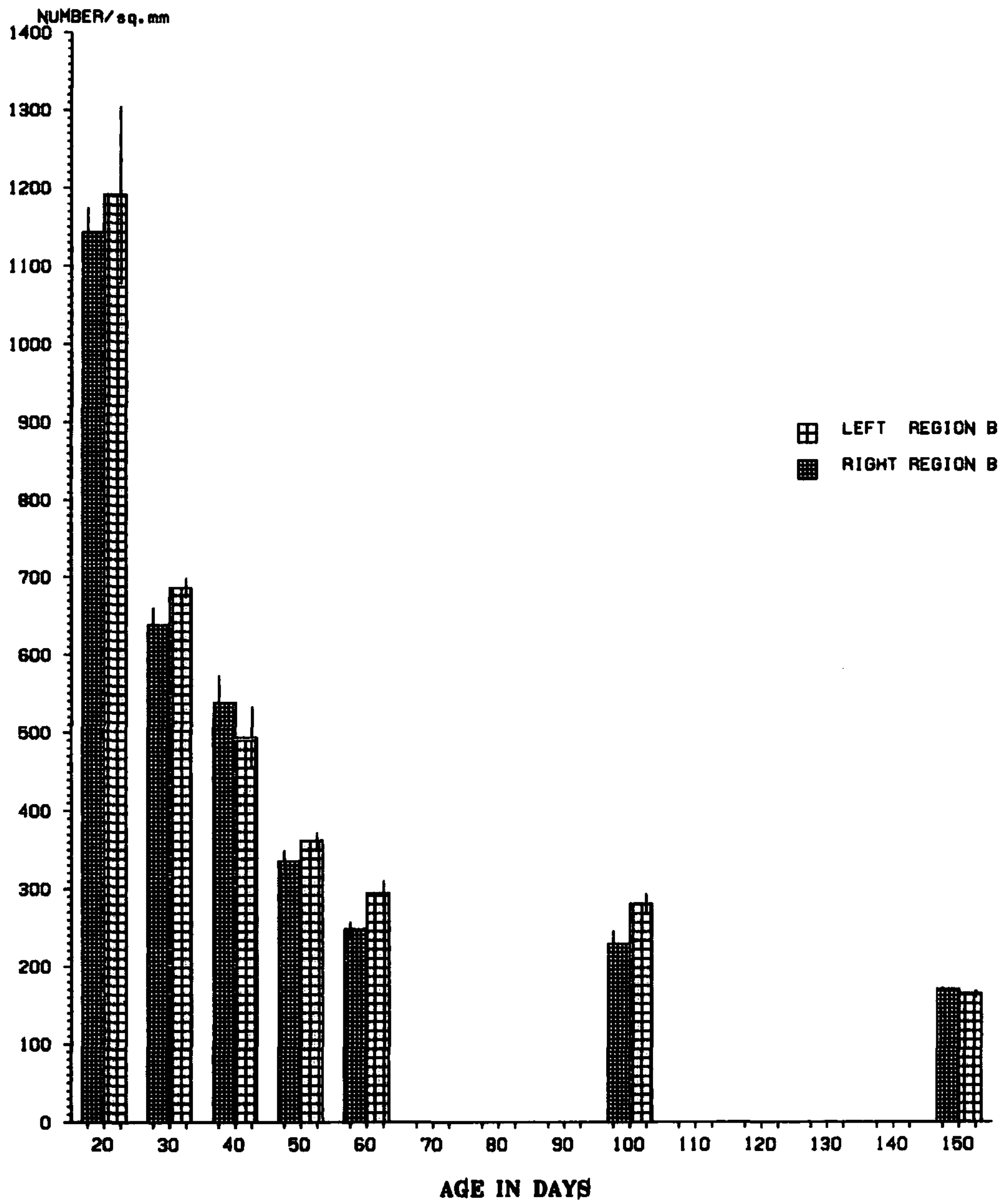


FIGURE 4.14 – TOTAL NUMBER OF MUSCLE FIBRES IN CONTROL CHICKENS (REGION B)



4.3.1.2 White Fibres (FG)

- Region A

The white-fibre number per square millimeter was not significantly different between the right and left side in control chickens as shown in table 4.5 and figure 4.15.

- Region B

There were no significant differences between the right and left side in control chickens as shown in figure 4.16, except at age 60 days, when the left side had a significantly larger numbers than the right.

4.3.1.3 Intermediate Fibres (FOG)

- Region A

Data of the intermediate fibres number per square millimeter in region A are plotted in figure 4.17. There were no significant differences between the right and left side in the fibre number in control chickens as shown in table 4.5.

- Region B

Also there were no significant differences in intermediate-fibre number between the right and left side in control chickens as shown in figure 4.18.

4.3.1.4 Red Fibres (SO)

- Region A

Data of the number of red fibres in region A of the control chickens are plotted in figure 4.19. There were no significant differences between the right and left side

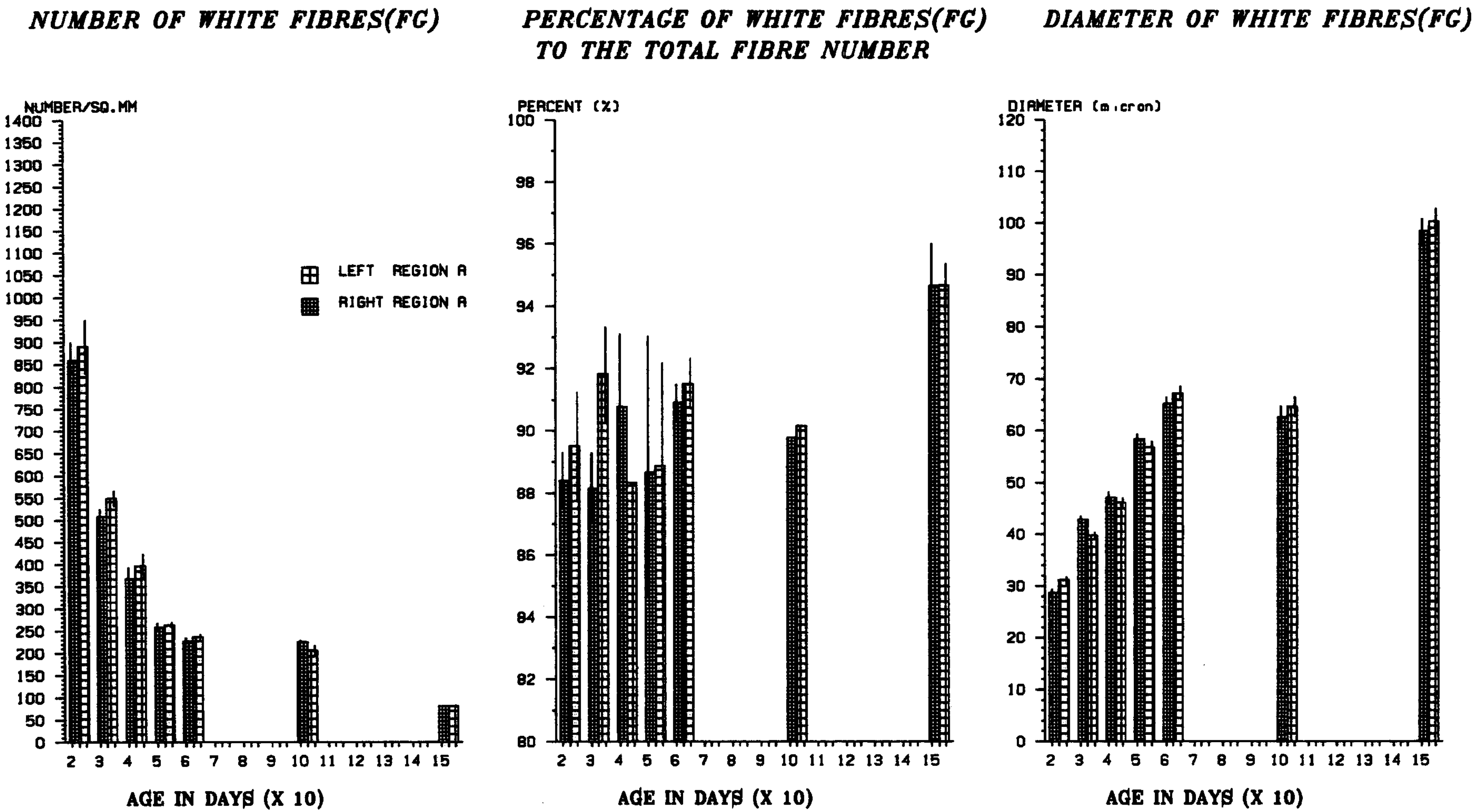


FIGURE 4.15 – WHITE FIBRES (FG) IN CONTROL CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

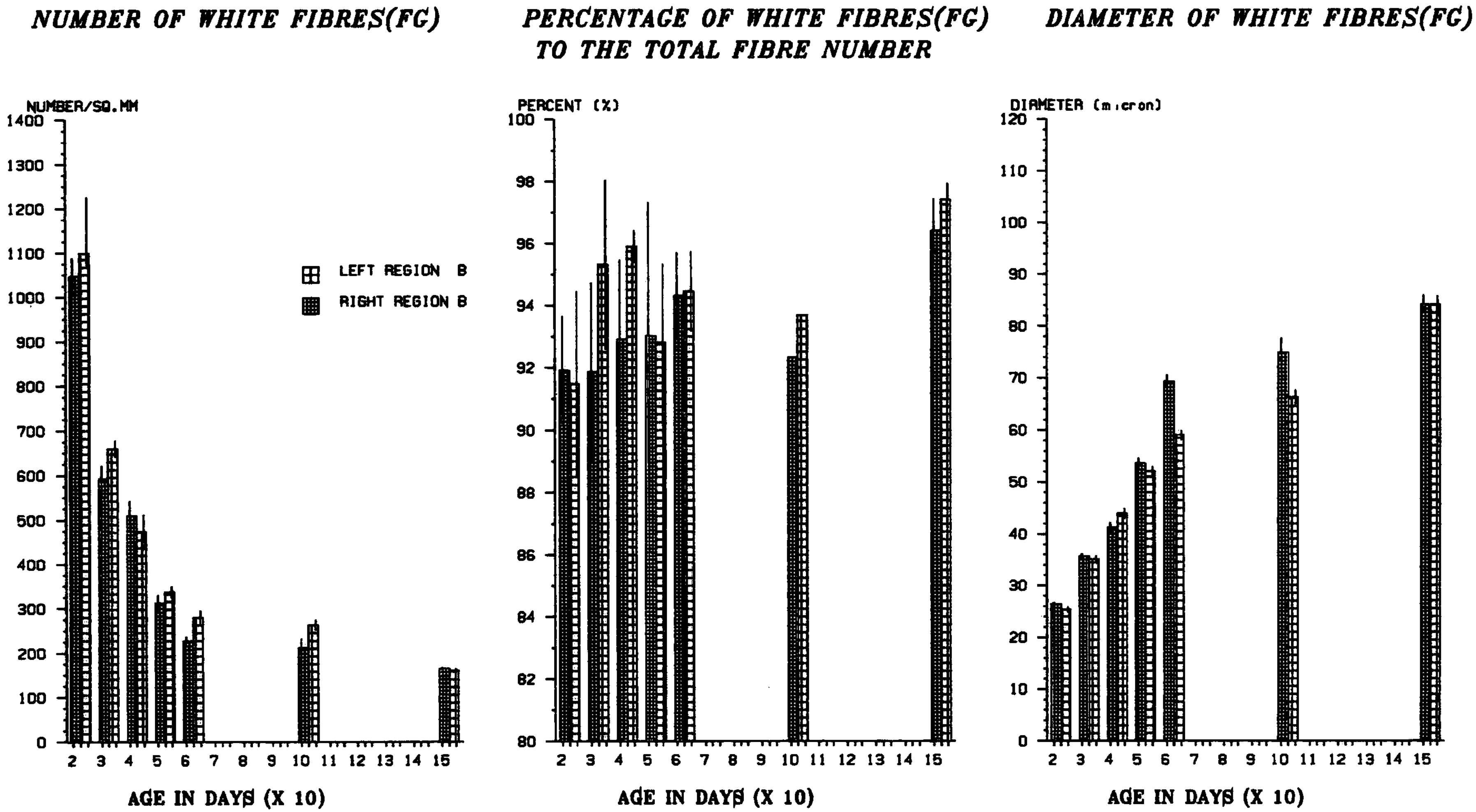


FIGURE 4.16 – WHITE FIBRES (FG) IN CONTROL CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

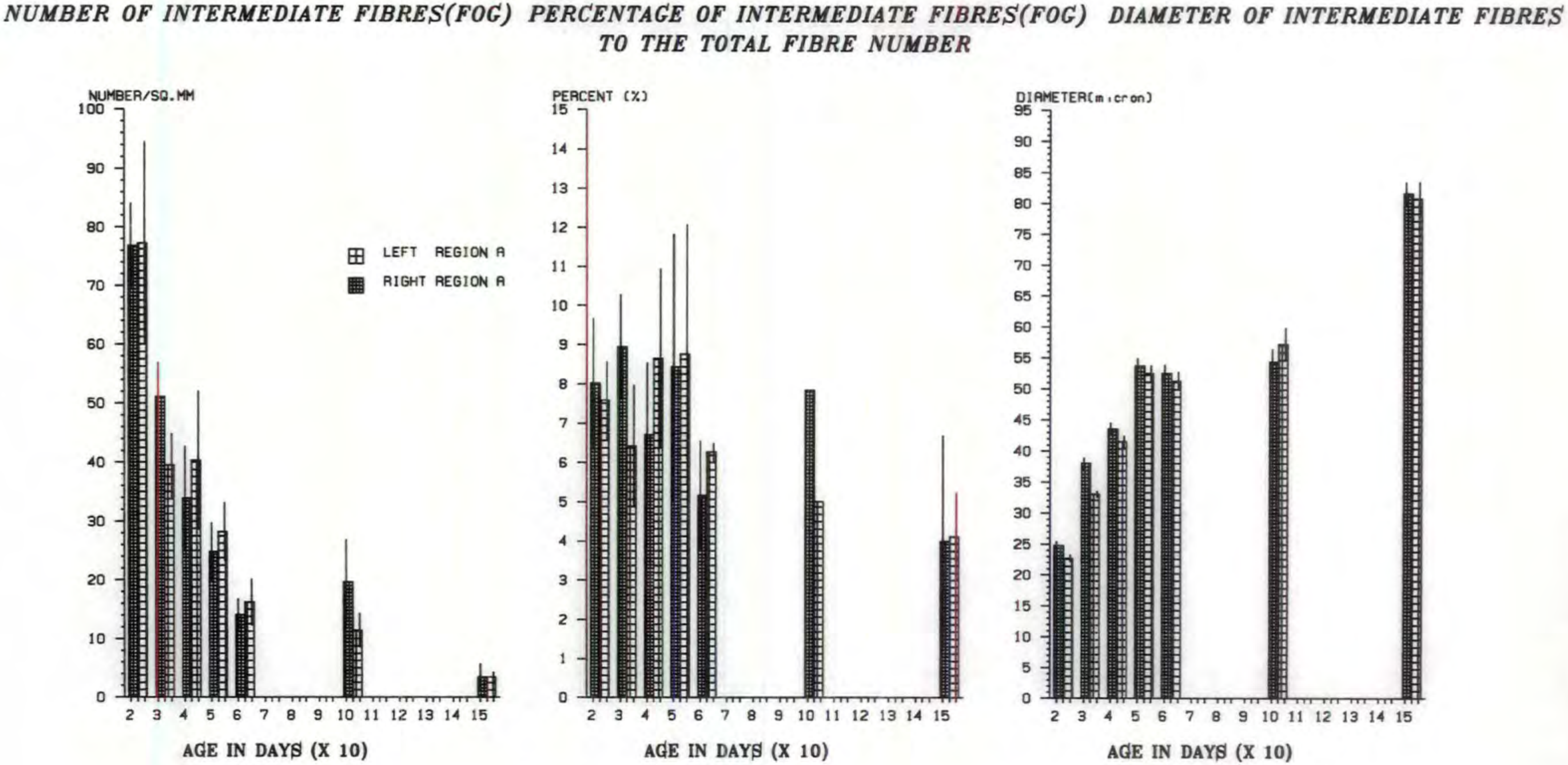


FIGURE 4.17 – INTERNEDIATE FIBRES (FOG) IN CONTROL CHICKENS (REGION A)

(OVERALL MEAN AND STANDARD ERROR)

NUMBER OF INTERMEDIATE FIBRES(FOG) *PERCENTAGE OF INTERMEDIATE FIBRES(FOG) TO THE TOTAL FIBRE NUMBER* *DIAMETER OF INTERMEDIATE FIBRES*

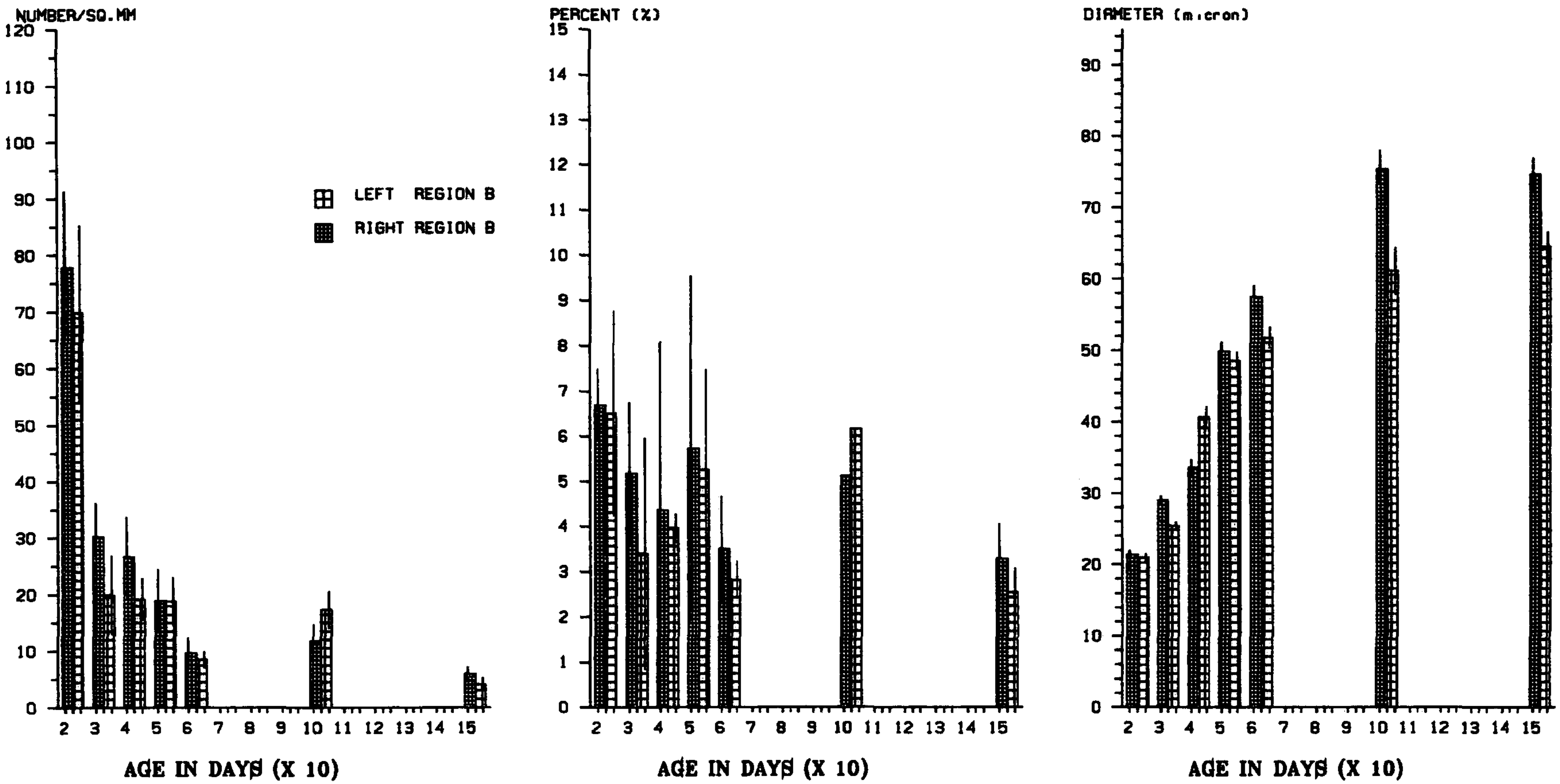


FIGURE 4.18 – INTERMEDIATE FIBRES(FOG) IN CONTROL CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

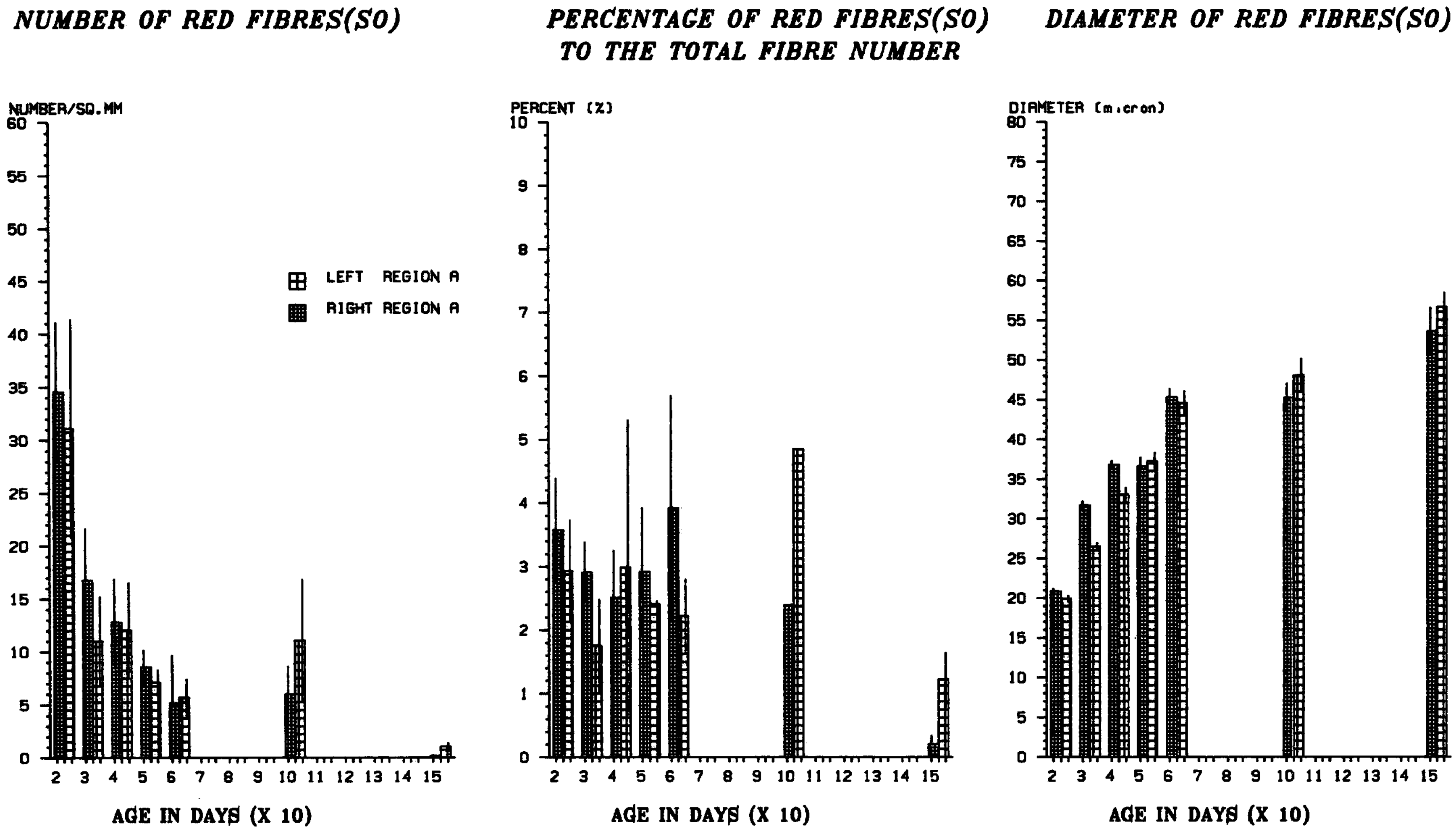


FIGURE 4.19 – RED FIBRES(SO) IN CONTROL CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

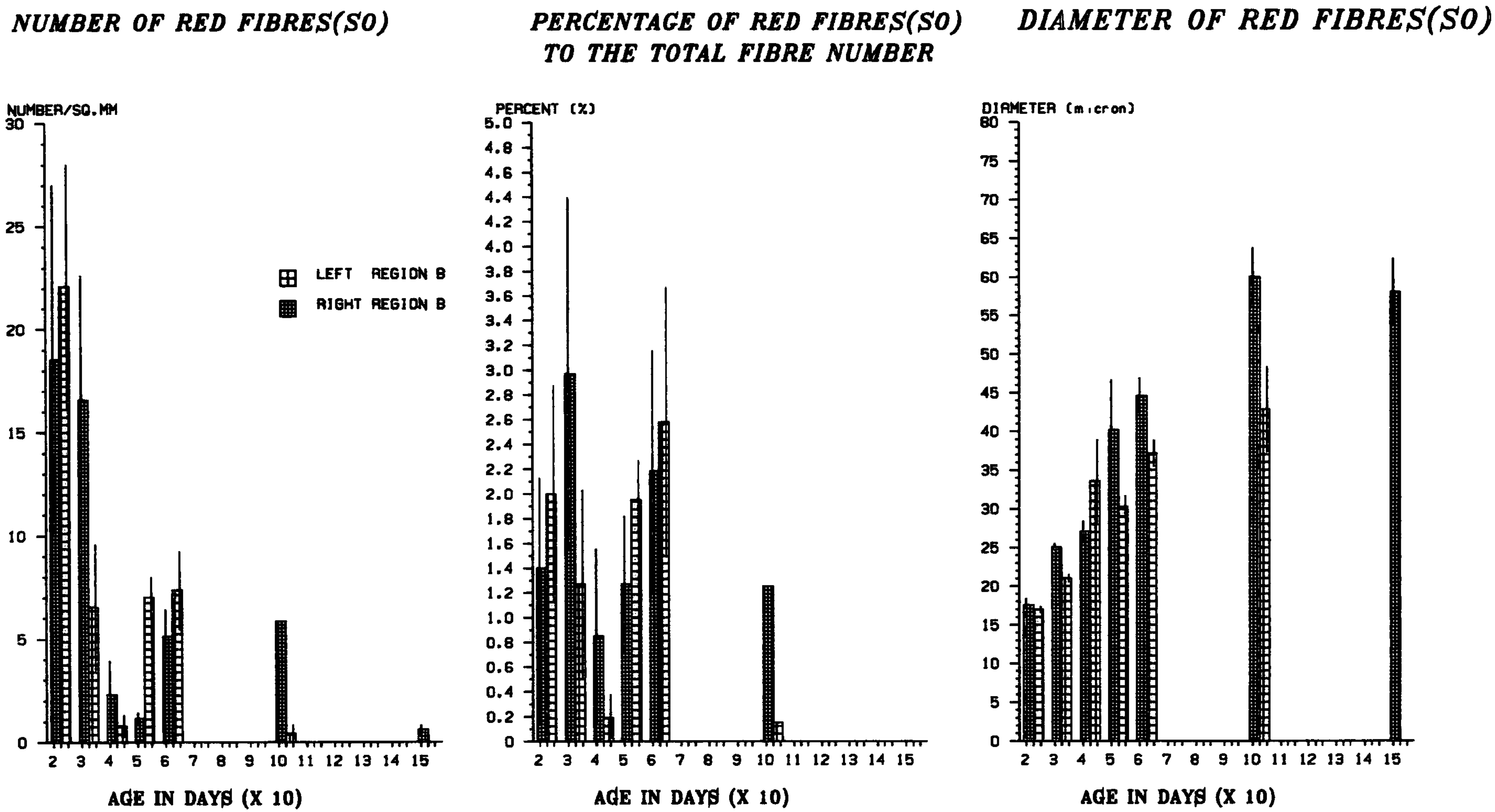


FIGURE 4.20 – RED FIBRES(SO) IN CONTROL CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

in this region of the control chickens as shown in table 4.5.

- Region B

Similarly, there were no significant differences in red-fibre number between the right and left side of region B in control chickens as shown in figure 4.20 and table 5.5.

4.3.2 Diameter of Fibres

The overall mean diameter of fibres for each age group was derived from the individual bird data in the appendix C. Data are presented for each fibre type in tables 4.1 and 4.2 for control and selected chickens respectively.

4.3.2.1 Whites Fibre (FG)

- Region A

There were some significant differences between the two sides of the pectoralis muscle fibre diameters in control chickens as shown in table 4.5 and figure 4.15. White-fibre diameter in both right and left region A were not significantly different, except at age 20 days when the left pectoralis muscle had significantly larger white-fibre diameter than the right in region A, and age 30 when the right side had larger white-fibre diameter.

- Region B

There were no significant differences in the diameter of the white-fibres between the right and left sides in control chickens except at age 60. At this age the right pectoralis muscle had significantly larger white-fibres (see figure 4.12).

4.3.2.2 Intermediate Fibres (FOG)

- Region A

The intermediate-fibre diameter was usually not significantly different between the right and left sides of region A. However the right pectoralis muscle in the control chickens had significantly larger intermediate-fibre diameter than the left pectoralis muscle in region A at ages 20 and 30 days (see figure 4.17).

- Region B

The diameter of the intermediate fibres was significantly larger in the right side of the control pectoralis muscle at ages 30, 60 and 150 days with exception of age 40 where the left side had larger intermediate-fibres as shown figure 4.18.

4.3.2.3 Red Fibres (SO)

- Region A

Red-fibre diameter in the right pectoralis muscle in the control chickens was significantly larger than the left pectoralis muscle in region A only at age 40 as shown in table 4.5 and figure 4.19.

- Region B

The diameter of the red fibres in the control chickens was significantly different between the two sides at ages 30 and 60 days only. At age 30 days the left pectoralis muscle was significantly larger in red-fibres diameter, whereas at age 60 days the right pectoralis muscle was significantly larger in diameter as shown in table 4.5 and figure 4.20.

In summary, pectoralis muscle in control chickens is not uniform. Fibre types are significantly different between the two regions studied, A and B, which represent the anterior and mid part of the pectoralis muscle. Region B has significantly larger total number of fibres and larger white-fibre number per square millimeter. This difference in fibres number was due to the larger diameters of all fibres type in region A than in the region B. Moreover, red fibres number per square millimeter was significantly larger in region A at the early age (20 to 50 days) than in region B.

Neither fibre-type number per square millimeter nor fibre diameter were, in general, significantly different in the right and left sides in both regions.

4.4 Right Vs. Left side of Pectoralis Muscle in Selected Chickens

Fibre types number per square millimeter and diameter were calculated in a similar way to the control chickens. Data of the overall mean fibre-type number and diameter are presented in table 4.2.

As with control chickens there were differences between the two regions, A and B, in fibre-types number and diameter. Student's t-test results are presented in table 4.6, therefore no detail is needed for the comparison between regions A and B.

However, numbers and diameters of fibres in the left pectoralis muscle in both regions A and B in selected chickens were compared to their corresponding regions in the right pectoralis muscle using Student's t-test to reveal any asymmetrical structure in both right and left pectoralis muscle.

4.4.1 Number of Fibres Per Square Millimeter

Total fibre number per square millimeter was not significantly different be-

Table 4.6 — Result of the *t*-test on the Average Number and Diameter Fibre Types in Regions A and B of the Pectoralis Muscle in Selected Chickens

Age (days)	Bird No.	Side and Region	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
20	3	RA/RB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		LA/LB	2.142^{*a}	2.478^{*a}	N.S.	N.S.	3.812^{***a}	N.S.	3.936^{***a}
30	2	RA/RB	N.S.	N.S.	3.317^{**b}	2.544^{*b}	N.S.	N.S.	5.690^{***a}
		LA/LB	N.S.	N.S.	5.064^{***b}	3.694^{**b}	N.S.	2.646^{*a}	3.249^{**a}
40	3	RA/RB	N.S.	N.S.	2.971^{**b}	3.120^{**b}	N.S.	3.677^{***a}	6.010^{***a}
		LA/LB	N.S.	N.S.	3.439^{**b}	2.970^{**b}	2.549^{*a}	N.S.	N.S.
50	3	RA/RB	-	2.259^{*b}	5.100^{***b}	3.924^{***b}	-	N.S.	3.322^{***a}
		LA/LB	-	N.S.	5.498^{***b}	5.324^{***b}	-	2.246^{*b}	7.155^{***a}
60	3	RA/RB	2.618^{*a}	3.630^{**b}	5.662^{***b}	2.800^{**b}	N.S.	N.S.	N.S.
		LA/LB	N.S.	2.218^{*a}	4.276^{***b}	N.S.	N.S.	N.S.	5.046^{***a}
100	3	RA/RB	N.S.	2.317^{*a}	7.007^{***b}	5.371^{***b}	N.S.	N.S.	3.520^{***a}
		LA/LB	N.S.	2.177^{*a}	7.651^{***b}	9.655^{***b}	5.028^{***a}	N.S.	5.749^{***a}
150	1	RA/RB	N.S.	N.S.	6.185^{***b}	6.574^{***b}	N.S.	N.S.	3.668^{***a}
		LA/LB	N.S.	N.S.	6.731^{***b}	6.148^{***b}	-	N.S.	7.144^{***a}

Number of asterisks indicates degree of significance of the t-test. a or b indicates the A or B region which is larger in number or diameter of the fibre type.

tween the two sides of pectoralis muscle either in region A or B, with exception of the right region A at ages 50 and 60 days which had a significantly larger total fibre number per square millimeter than the left (see figure 4.21). In contrast, at age 60 days, left pectoralis muscle in region B had significantly larger total fibre number per square millimeter (see figure 4.22). This might be due to the small number of white fibres in region B as shown in table 4.7.

Table 4.7 — Result of t-test Between RA Vs. LA and RB Vs. LB of the Average Number and Diameter of Fibres in Pectoralis Muscle in Selected Chickens

Age (days)	No. of Birds	Side and Region	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
20	3	RA/LA	N.S.	N.S.	N.S.	N.S.	2.515^{*R}	N.S.	3.390^{***R}
		RB/LB	N.S.	N.S.	N.S.	N.S.	6.924^{***R}	2.024^{*R}	6.421^{***R}
30	2	RA/LA	N.S.	N.S.	N.S.	N.S.	N.S.	2.645^{**L}	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	2.475^{*L}
40	3	RA/LA	N.S.	N.S.	N.S.	N.S.	3.615^{***R}	N.S.	4.460^{***R}
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	1.995^{*L}	N.S.
50	3	RA/LA	N.S.	N.S.	N.S.	2.804^{**R}	3.241^{**L}	3.391^{***L}	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	2.201^{*R}
60	3	RA/LA	N.S.	N.S.	N.S.	1.978^{*R}	N.S.	N.S.	2.526^{*L}
		RB/LB	N.S.	N.S.	2.050^{*R}	2.421^{*L}	2.591^{*R}	N.S.	2.574^{*R}
100	3	RA/LA	N.S.	N.S.	N.S.	N.S.	2.537^{*L}	3.577^{***L}	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	2.240^{*R}	N.S.	N.S.
150	1	RA/LA	N.S.	N.S.	N.S.	N.S.	5.876^{***L}	N.S.	N.S.
		RB/LB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Number of asterisks indicates degree of significance of the t-test. R or L indicates the right or left side which is significantly larger in number or diameter of the fibre type.

Moreover, fibre-type number per square millimeter was not significantly different between the right and left side of pectoralis muscle in both regions, as shown in table 4.7 and figures 4.23 to 4.28, except at age 60 days when right region B had significantly larger (t = 2.05, p> 0.05) white-fibre number than its corresponding region in the left side

FIGURE 4.21 – TOTAL NUMBER OF MUSCLE FIBRES IN SELECTED CHICKENS (REGION A)

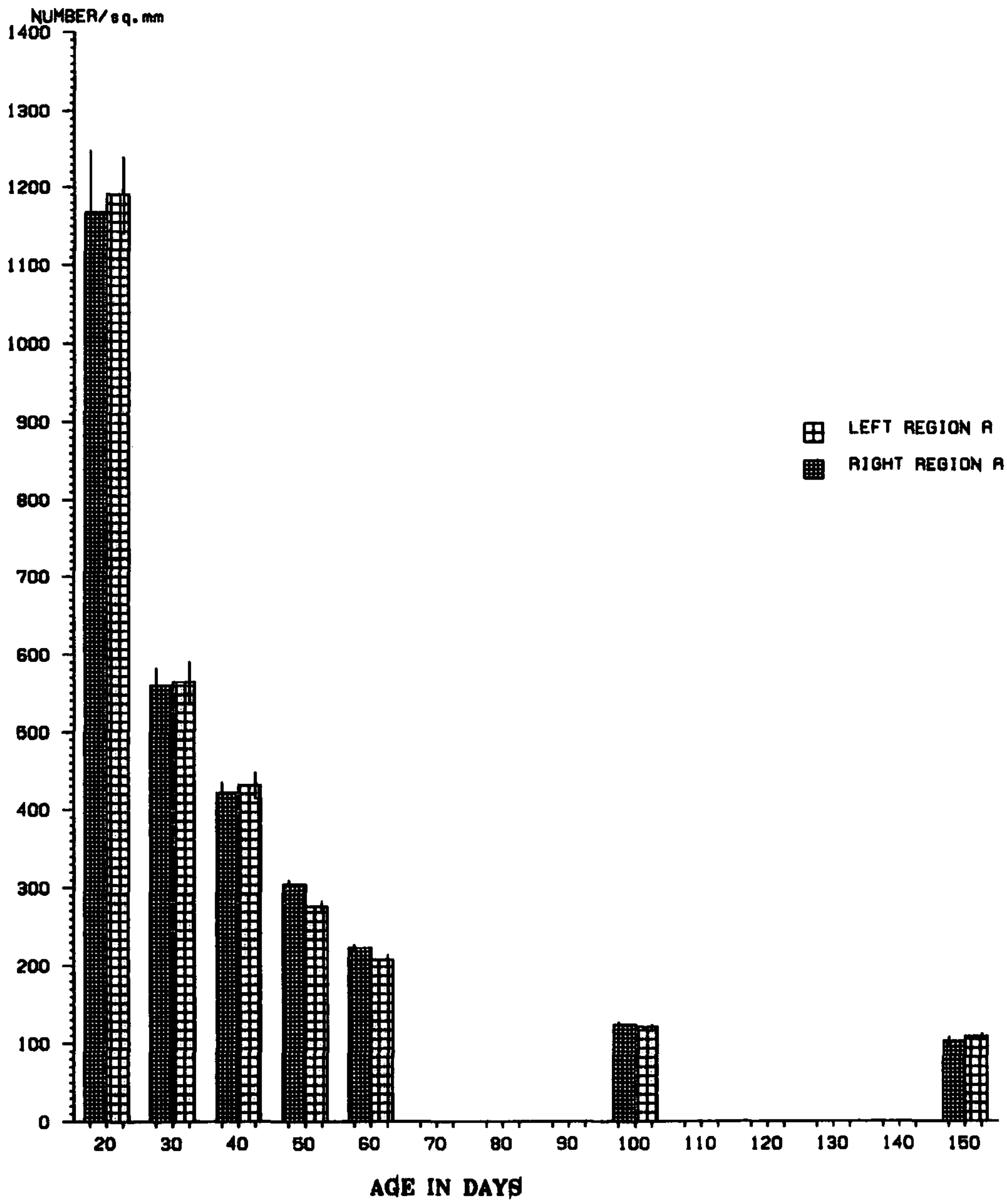
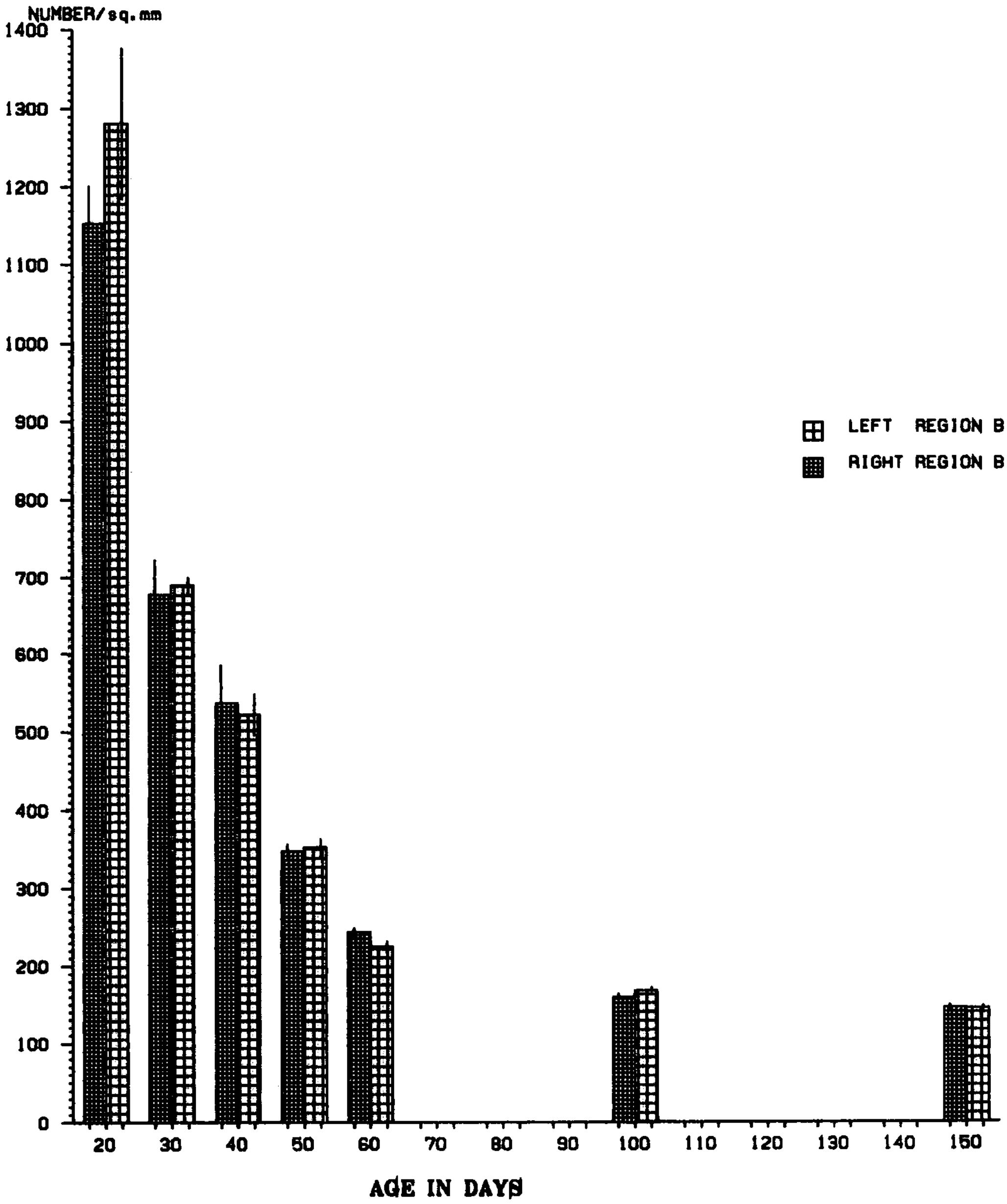


FIGURE 4.22 – TOTAL NUMBER OF MUSCLE FIBRES IN SELECTED CHICKENS (REGION B)



NUMBER OF WHITE FIBRES(FG) *PERCENTAGE OF WHITE FIBRES(FG) TO THE TOTAL FIBRE NUMBER* *DIAMETER OF WHITE FIBRES(FG)*

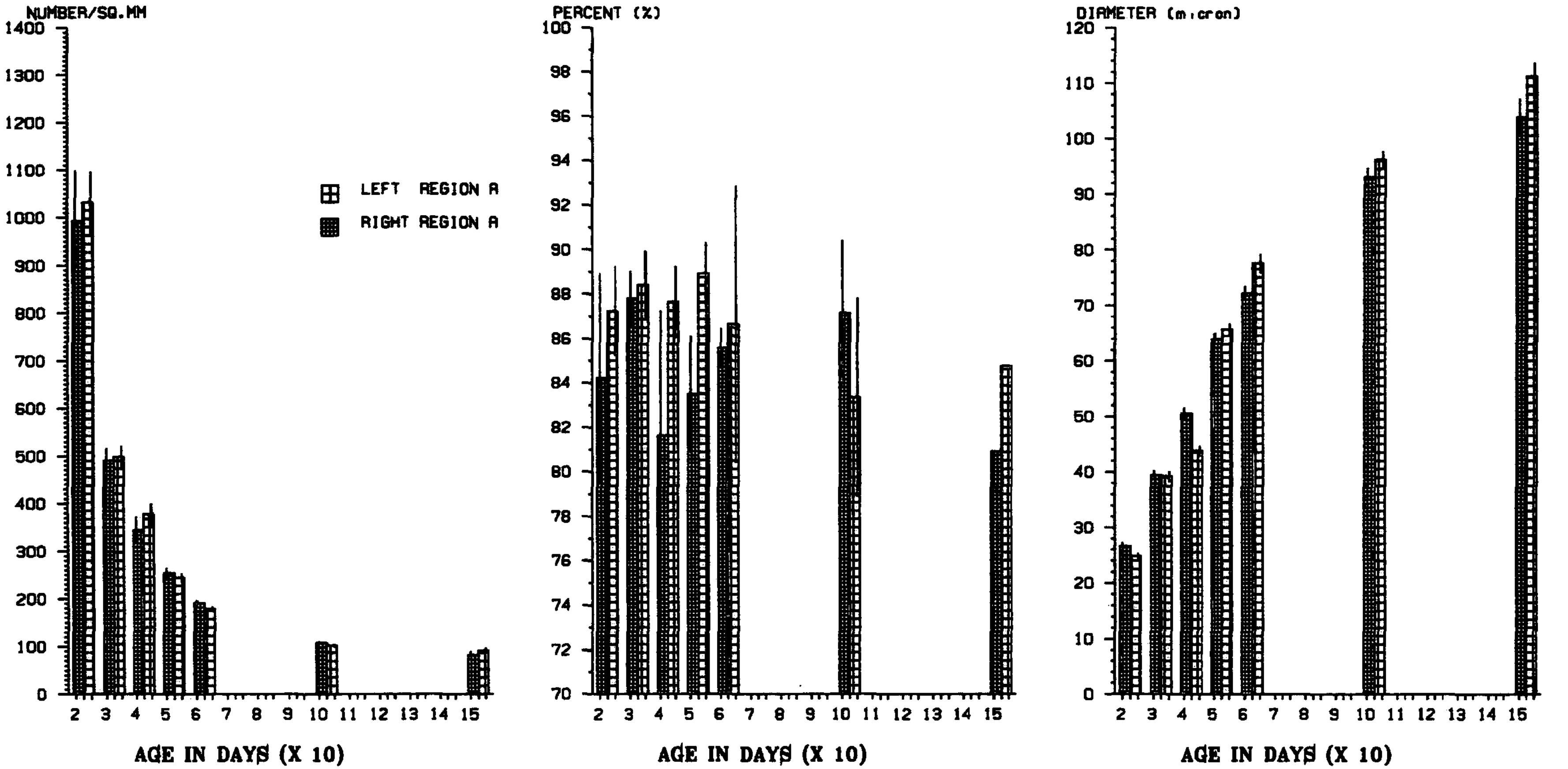


FIGURE 4.23 – WHITE FIBRES(FG) IN SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

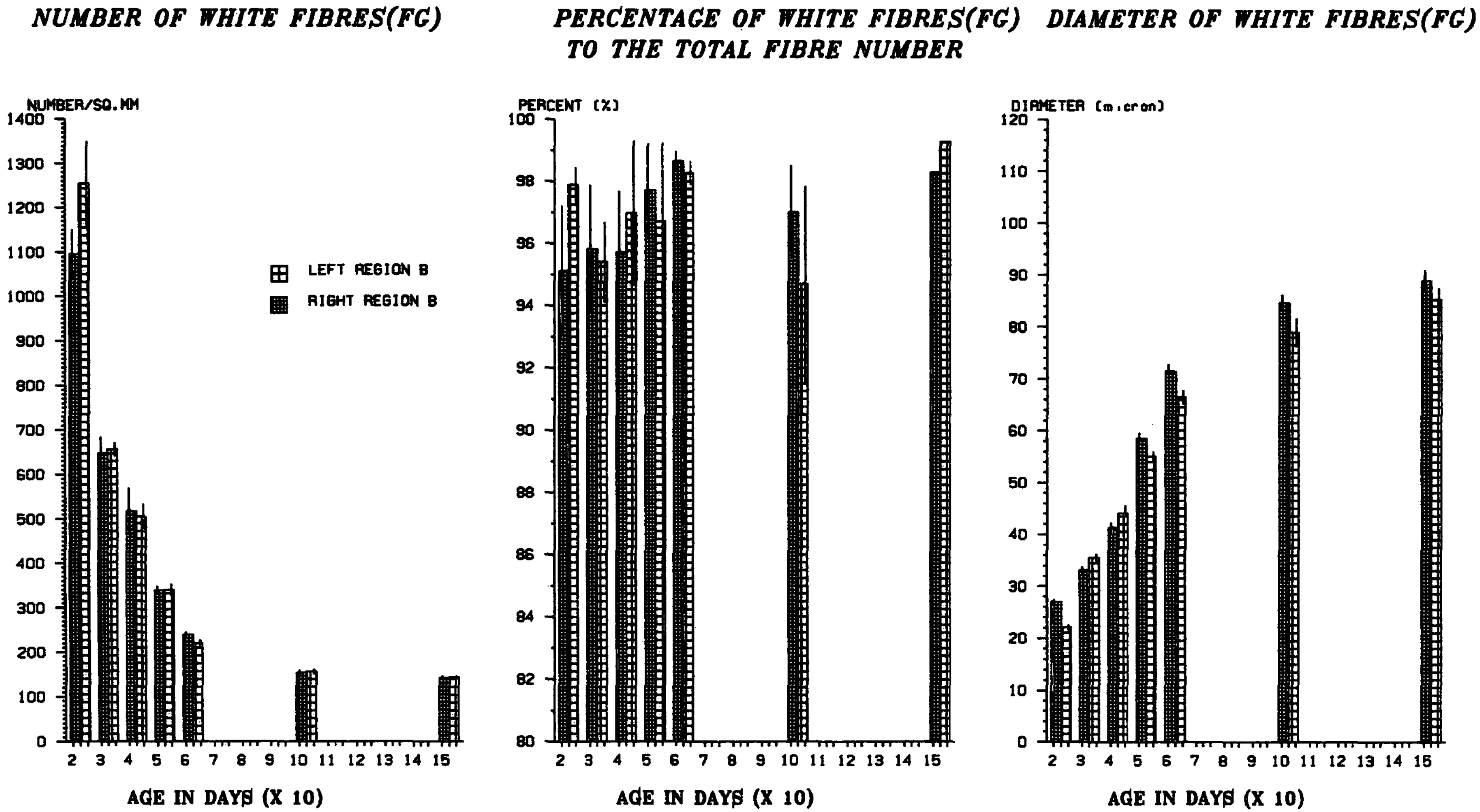


FIGURE 4.24 WHITE FIBRES(FG) IN SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

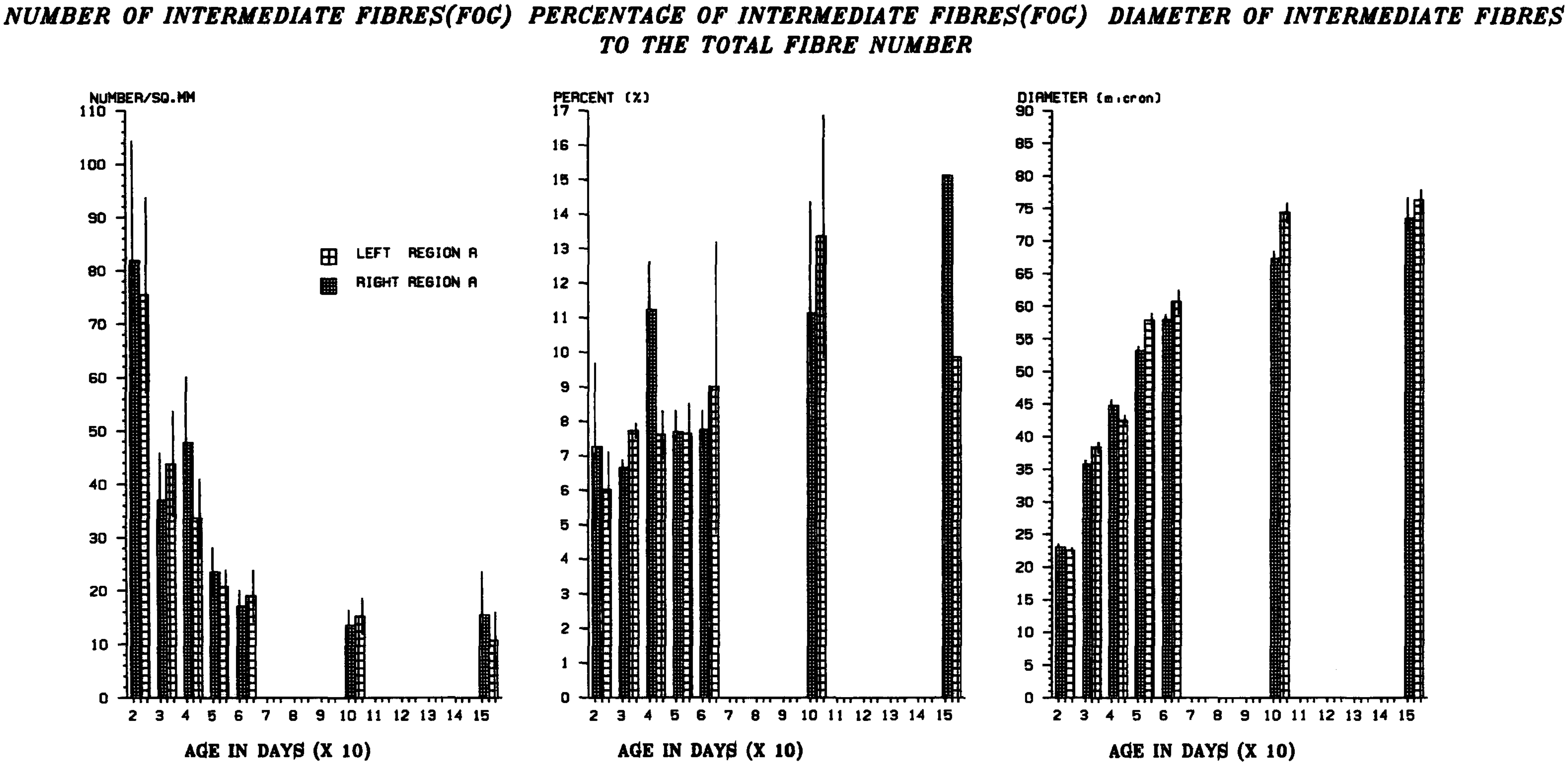


FIGURE 4.25 – INTERMEDIATE FIBRES(FOG) IN SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

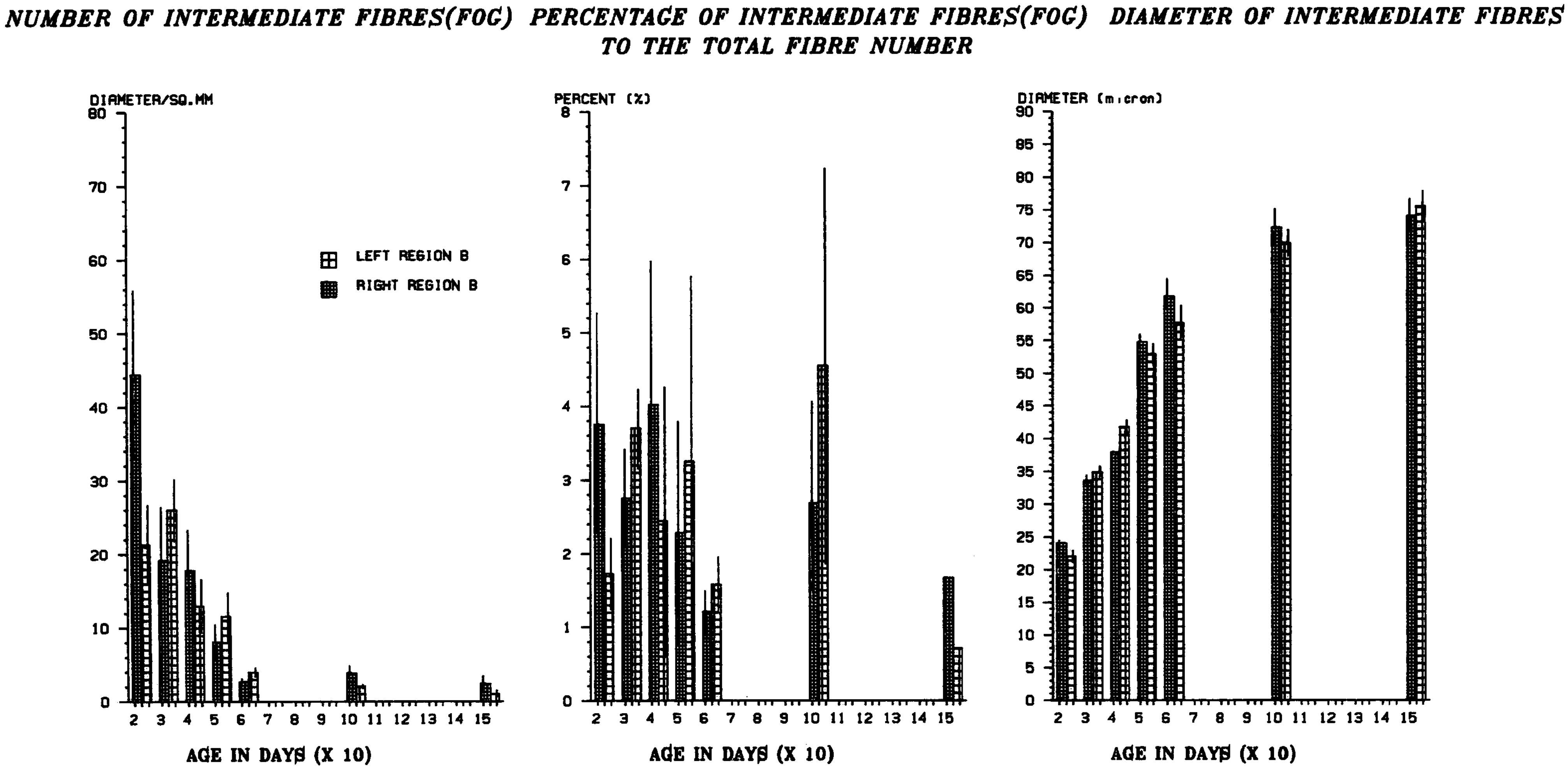


FIGURE 4.26 – INTERMEDIATE FIBRES(FOG) IN SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

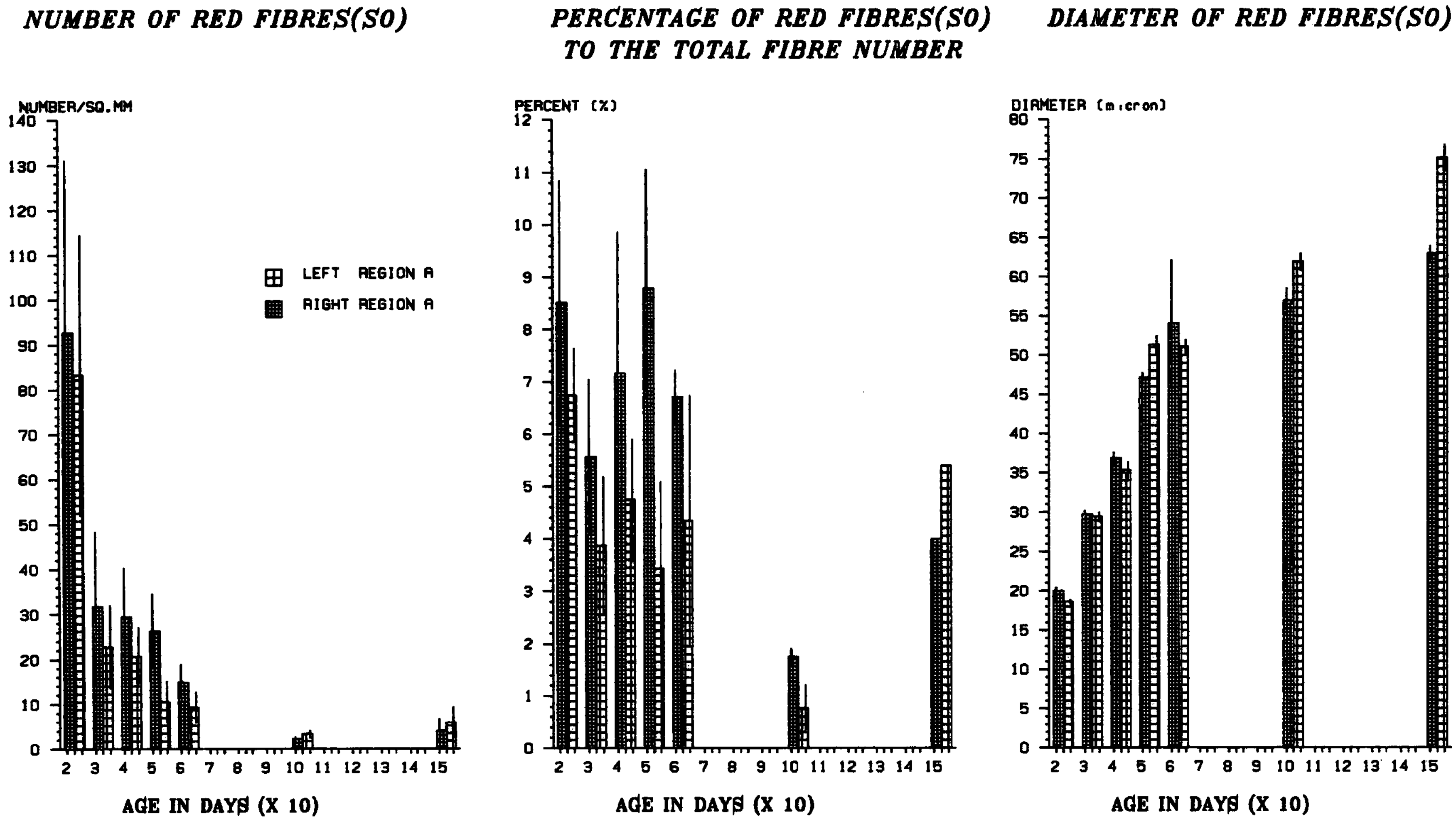


FIGURE 4.27 – RED FIBRES(SO) IN SELECTED CHICKENS (REGION A)

(OVEALL MEAN WITH STANDARD ERROR)

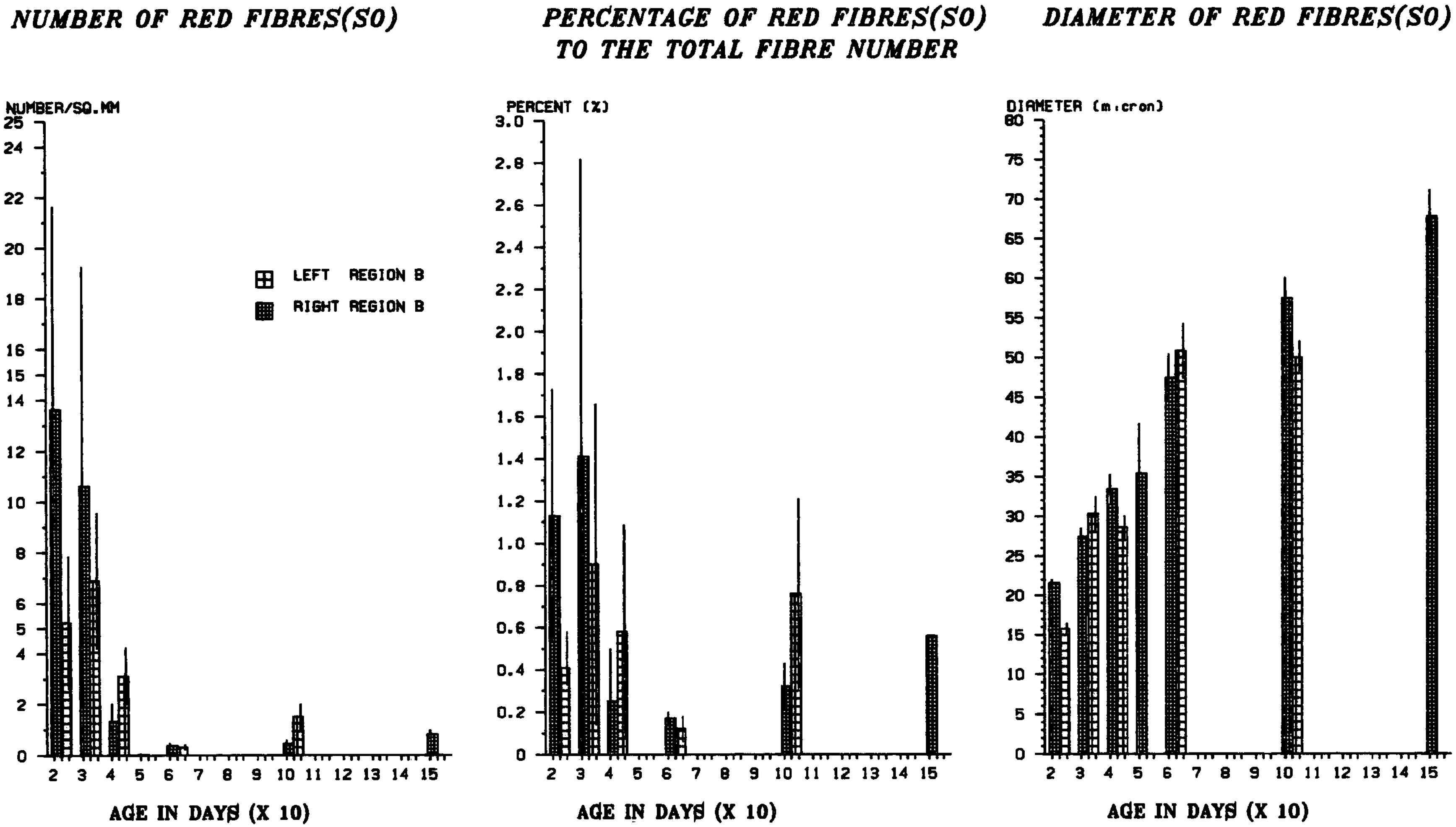


FIGURE 4.28 – RED FIBRES(SO) IN SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

Table 4.8 — Mean Number of Muscle Fibres by Type as Percentages to the Total Numbers in Right and Left Pectoralis Muscles in Selected Chickens

Region	Fibre Type	Side	20	30	40	50	60	100	150†
A	White	R	84.23 ± 4.72	87.80 ± 1.25	81.63 ± 5.61	83.49 ± 2.63	85.56 ± 0.90	87.14 ± 3.30	80.91
		L	87.24 ± 2.01	88.40 ± 1.54	87.65 ± 1.60	88.93 ± 1.40	86.65 ± 6.23	83.36 ± 4.47	84.76
	Intermediate	R	7.26 ± 2.44	6.65 ± 0.24	11.22 ± 1.40	7.68 ± 0.63	7.74 ± 0.57	11.12 ± 3.24	15.11
		L	6.02 ± 1.11	7.73 ± 0.22	7.61 ± 0.70	7.63 ± 0.89	9.00 ± 4.12	13.35 ± 3.52	9.85
	Red	R	8.51 ± 2.34	5.56 ± 1.49	7.16 ± 2.70	8.78 ± 2.28	6.70 ± 0.53	1.75 ± 0.16	3.99
		L	6.74 ± 0.91	3.87 ± 1.32	4.74 ± 1.17	3.43 ± 1.66	4.34 ± 2.40	0.76 ± 0.45	5.39
B	White	R	95.10 ± 2.11	95.82 ± 2.05	95.70 ± 1.99	97.69 ± 1.52	98.63 ± 0.33	97.01 ± 1.50	98.28
		L	97.88 ± 0.56	95.40 ± 1.30	96.97 ± 2.33	96.71 ± 2.53	98.27 ± 0.38	94.69 ± 3.14	99.27
	Intermediate	R	3.75 ± 1.53	2.75 ± 0.67	4.02 ± 1.96	2.28 ± 1.52	1.21 ± 0.29	2.68 ± 1.39	1.67
		L	1.73 ± 0.49	3.70 ± 0.54	2.44 ± 1.83	3.25 ± 2.53	1.58 ± 0.38	4.55 ± 2.69	0.71
	Red	R	1.13 ± 0.60	1.41 ± 1.41	0.25 ± 0.25	–	0.17 ± 0.03	0.32 ± 0.11	0.56
		L	0.41 ± 0.07	0.90 ± 0.76	0.58 ± 0.51	–	0.12 ± 0.06	0.76 ± 0.45	–

Mean± SE is given for each measurement.

†One bird only.

The percentage of fibre-type number per square millimeter to the total fibre number were not significantly different between right region A or region B to their corresponding regions in the left side as shown in table 4.8.

4.4.2 Diameter of Fibres

Data of the over mean diameter of fibres in selected chickens are presented in table 4.2, Student's *t*-test was carried on the diameter of fibres between the right regions A and B and their corresponding regions in the left side. The results are presented in table 4.7.

4.4.2.1 White Fibre (FG)

- Region A

The diameter of white fibres was not significantly different between the two sides after 60 days of age. However, the right region A had significantly larger white-fibre diameter than its corresponding region in the left pectoralis muscle at age 20 and 40 days, whereas, at age 60 days the left had larger white-fibre diameter than the right (see figure 4.23).

- Region B

In general, there were no significant differences between the two sides of region B of the pectoralis muscle, except at age 30 days when the left region B had significantly larger white fibres than the right one, and at 60 days when the right region B had significantly larger white fibres than the left, as shown in table 4.7 and figure 4.24.

4.4.2.2 Intermediate Fibres (FOG)

- Region A

The left Pectoralis muscle in the selected chickens had significantly larger intermediate-fibre diameter in region A than its corresponding region in the right muscle at age 30, 50, and 100 days as shown in table 4.7 and figure 4.25.

- Region B

Intermediate-fibre diameter in region B was not significantly different between the right and left side of pectoralis muscle, except at age 20 days when right region B had significantly larger intermediate-fibre diameter than in the left side, and at age 40 days the left region B had significantly larger intermediate-fibre diameter than the right one as shown in table 4.7 and figure 4.26.

4.4.2.3 Red Fibres

- Region A

Red-fibre diameter in the pectoralis muscle in selected chickens was significantly larger in the right region A at early age (20 and 40 days), whereas the left side of pectoralis muscle had significantly larger red-fibre diameter in region A than its corresponding region in the right side in the old selected birds at age 50, 100, and 150 days as shown in table 4.7 and figure 4.27.

- Region B

Red-fibre diameters in region B in the right side of the pectoralis muscle in selected chickens had significantly larger diameter than the left side at ages 20, 60, and 100 days as shown in table 4.7 and figure 4.28.

In summary, the differences between region A and B of the pectoralis muscle in selected chickens were similar to the control chickens. However, fibre-type number per square millimeter was not consistently different between each of the right region A and B to their corresponding regions in the left side of pectoralis muscle. Fibre-type diameter in the right pectoralis muscle was some times significantly larger than in the left side particularly white- and red-fibre diameter.

4.5 Fibre Types in Control Vs. Selected Chickens

Number and diameter of pectoralis muscle fibres in the control and selected chickens was compared with age to discover whether the pectoralis muscle structure of control chickens differs at particular age. The comparison was taken between each region at each side in control chickens to its corresponding region in selected chickens.

4.5.1 Right Pectoralis Muscle

Comparison between the right region A and B in control and their corresponding regions in the right pectoralis muscle in selected chickens was made using Student's t-test. The results are given in table 4.9.

4.5.1.1 Total Fibres Number

- Region A

Total number of muscle fibres type per square millimeter was not consistently different in the right region A in control or selected chickens, as shown in table 4.9 and figure 4.29.

Table 4.9 — Result of t-test on the Average Number and Diameter of Fibre Types Between the Right Regions A and B in Control and their Corresponding Right Regions in Selected Chickens

Age	No. of	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
(days)	Birds C/S		Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
20	3/3	A	N.S.	N.S.	N.S.	2.333^{*s}	N.S.	2.170^{*c}	2.186^{*c}
		B	N.S.	N.S.	N.S.	N.S.	4.345^{***s}	3.495^{***s}	N.S.
30	3/2	A	N.S.	N.S.	N.S.	N.S.	3.800^{***c}	N.S.	2.859^{**c}
		B	N.S.	N.S.	N.S.	N.S.	2.225^{*s}	4.159^{***s}	2.948^{**c}
40	3/3	A	N.S.	N.S.	N.S.	2.188^{*c}	N.S.	N.S.	2.251^{*s}
		B	N.S.	N.S.	N.S.	N.S.	2.662^{*s}	2.279^{*s}	N.S.
50	3/3	A	2.059^{*s}	N.S.	N.S.	N.S.	8.002^{***s}	N.S.	3.527^{***s}
		B	–	2.052^{*c}	N.S.	N.S.	–	2.288^{*s}	3.113^{**s}
60	3/3	A	N.S.	N.S.	3.515^{***c}	2.853^{**c}	N.S.	3.357^{**s}	3.570^{***s}
		B	4.952^{***c}	3.255^{**c}	N.S.	N.S.	N.S.	N.S.	N.S.
100	1/3	A	2.198^{*c}	N.S.	12.680^{***c}	13.621^{***c}	4.082^{***s}	4.926^{***s}	9.506^{***s}
		B	3.813^{***c}	2.837^{**c}	3.568^{***c}	4.727^{***c}	N.S.	N.S.	3.097^{**s}
150	2/1	A	2.283^{*s}	N.S.	N.S.	5.164^{***s}	3.699^{***s}	2.745^{**c}	N.S.
		B	N.S.	N.S.	4.437^{***c}	4.273^{***c}	N.S.	N.S.	N.S.

Number of asterisks indicates degree of significance of the t-test. c or s indicates the control or selected chickens which is significantly larger in number or diameter of the fibre type.

- Region B

Muscle-fibre number per square millimeter in region B was not significantly different at early age, between control and selected chickens. However, the differences between them appeared to be significant at ages 100 and 150 days, when control chickens had significantly larger total fibre number per square millimeter than in selected chickens as shown in table 4.9 and figure 4.30.

FIGURE 4.29 – TOTAL FIBRE NUMBER IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

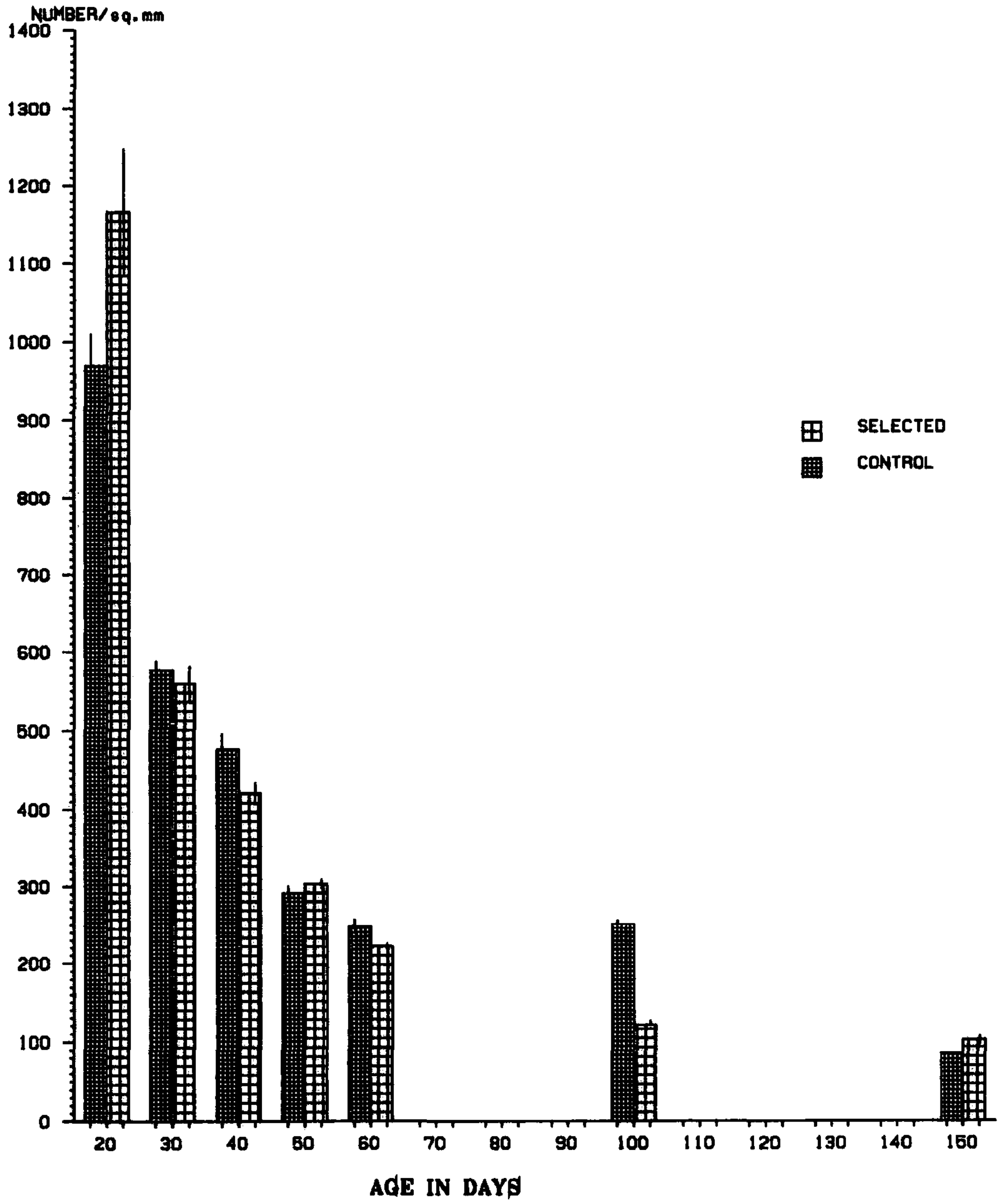
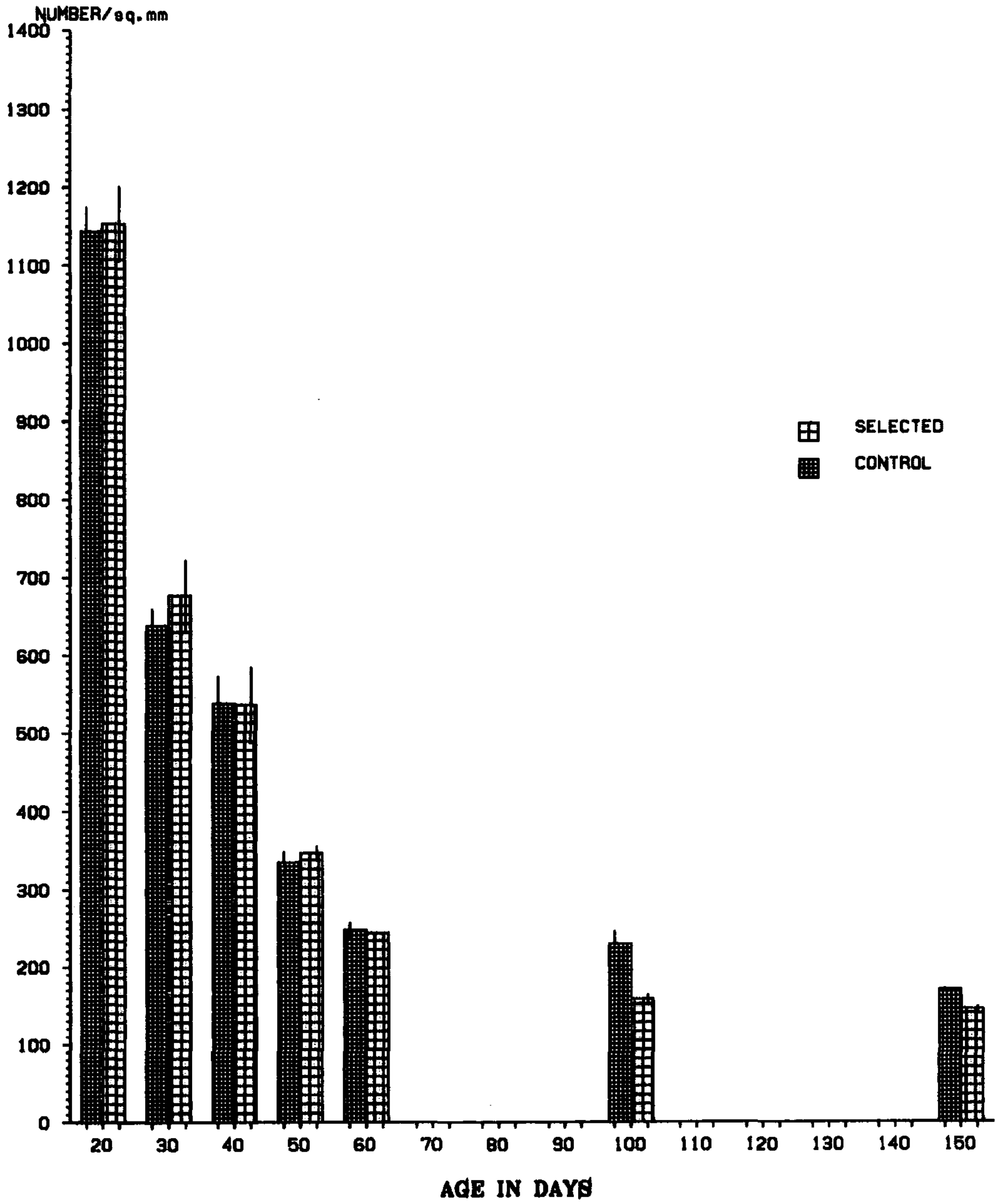


FIGURE 4.30 – TOTAL FIBRE NUMBER IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)



4.5.1.2 Fibre-Type Number

In general, fibre-type number per square millimeter in the control and selected chickens was not significantly different at early age (up to 50 days). Afterwards, differences became larger and significant too as shown in table 4.9. This might be due to the effect of increase in fibre-type diameter increase with age in the selected chickens. This effect will be discussed in the allometric growth of fibre types.

- Region A

There were no significant differences between white-, intermediate-, and red-fibre number per square millimeter of control and selected chickens, as shown in table 4.9 and figures 4.31, 4.32 and 4.33 for the white, intermediate, and red fibres type respectively.

- Region B

The result was similar to region A, as shown in table 4.9 and figures 4.34, 4.35, and 4.36 for the white, intermediate, and red fibres respectively.

4.5.1.3 Diameter of Muscle Fibres

There were no significant differences between fibre diameter of control and selected chickens at early age (20 and 30 days). However, from 40 days, significantly larger fibres nearly always occurred in selected chickens, as shown in table 4.9.

4.5.2 Left Pectoralis Muscle

Comparison between the left region A and B in control and their corresponding regions in the right pectoralis muscle in selected chickens was carried on using Student's *t*-test. The results are given in table 4.10.

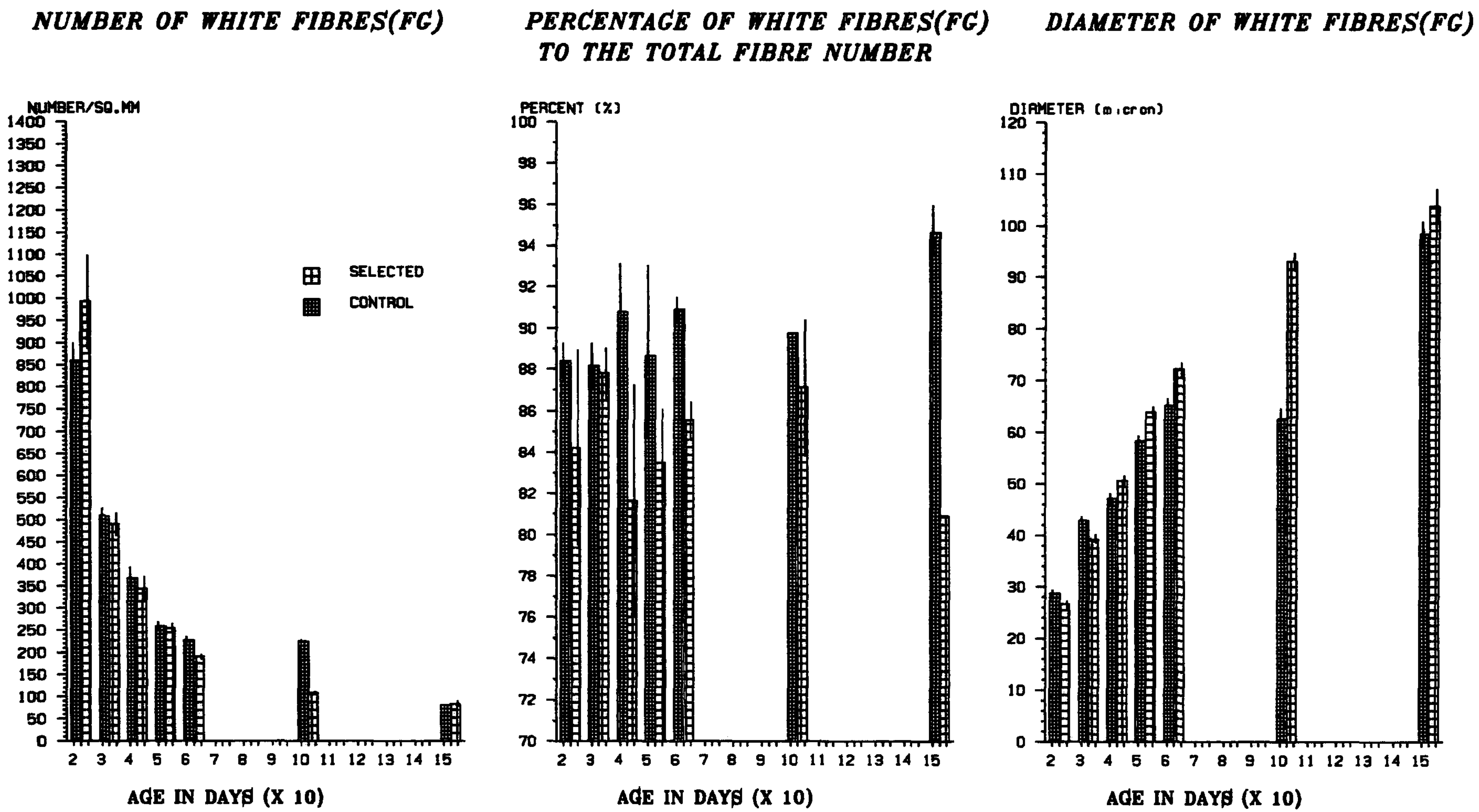


FIGURE 4.31 – WHITE FIBRES(FG) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

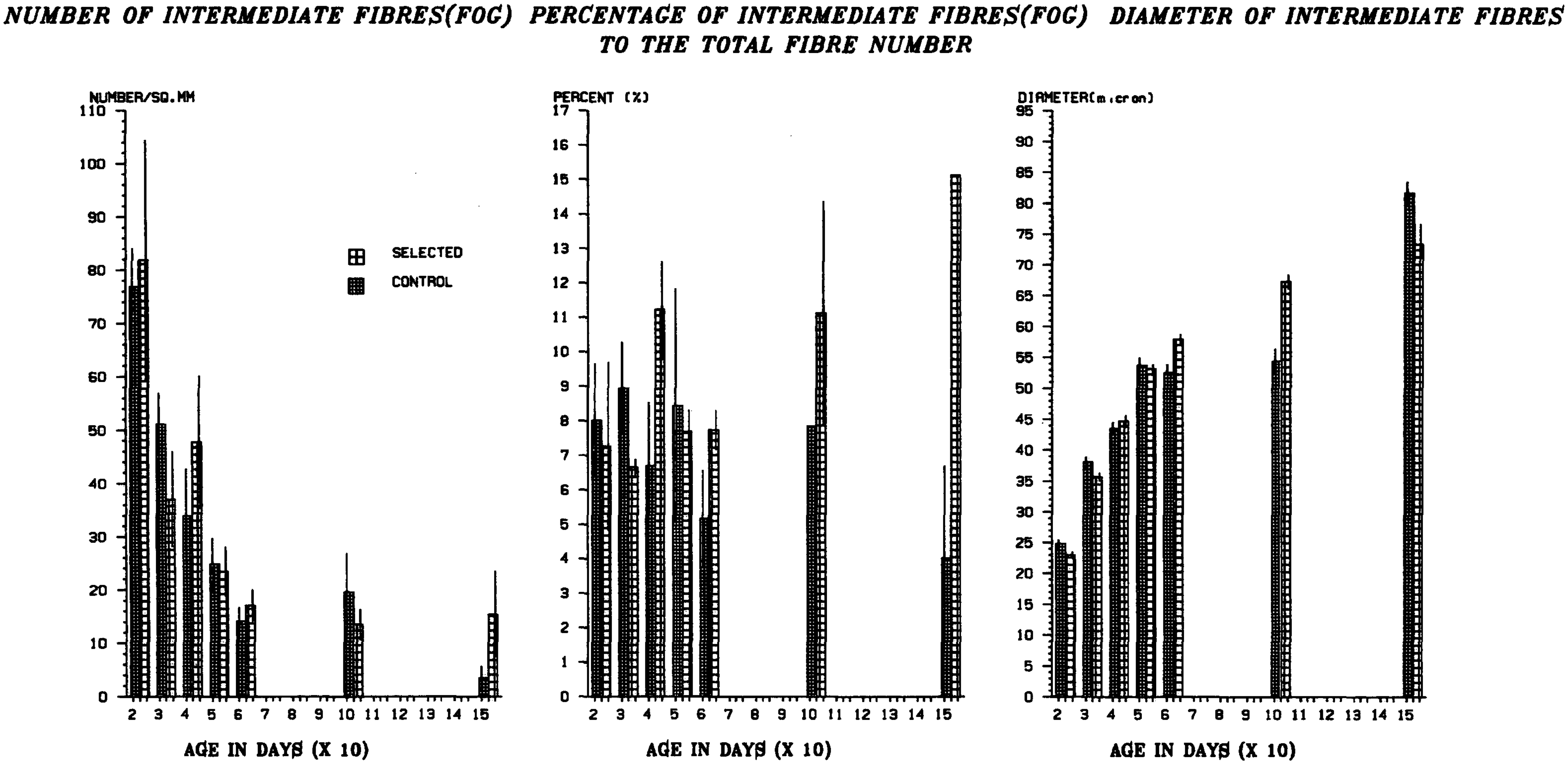


FIGURE 4.32 – INTERNEDIATE FIBRES(FOG) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVERALL MEAN AND STANDARD ERROR)

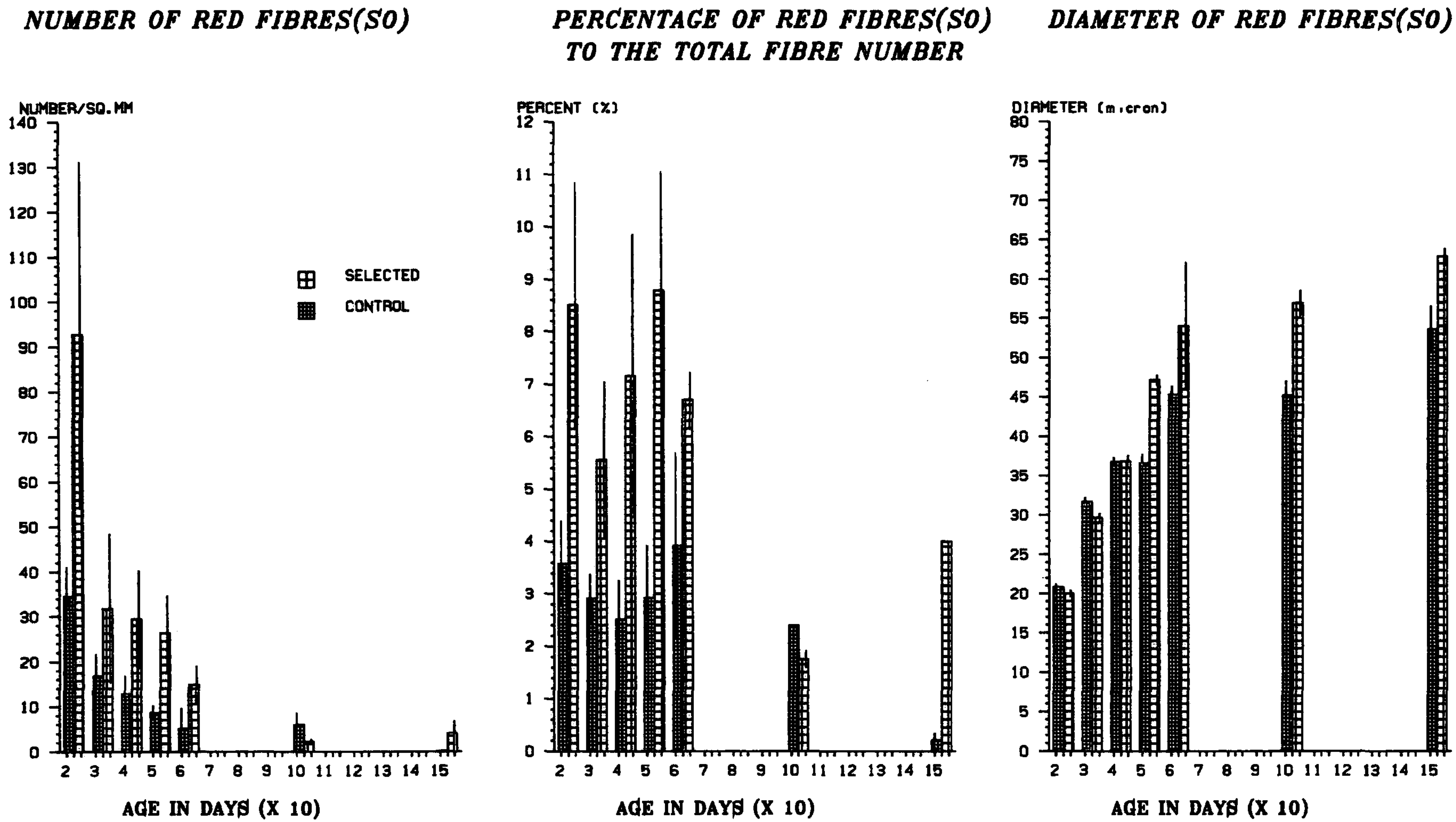


FIGURE 4.33 – RED FIBRES(SO) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

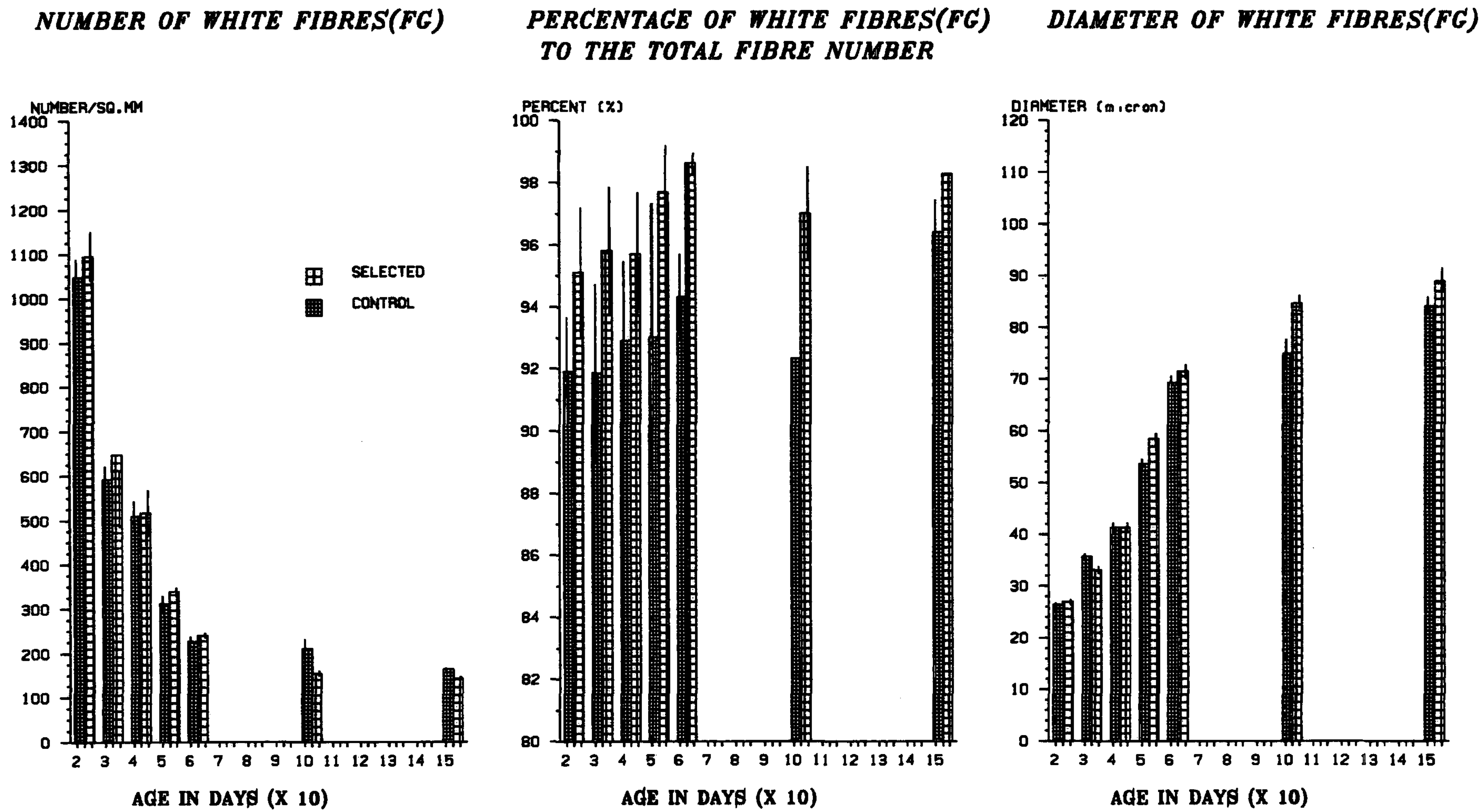


FIGURE 4.34 – WHITE FIBRES(FG) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

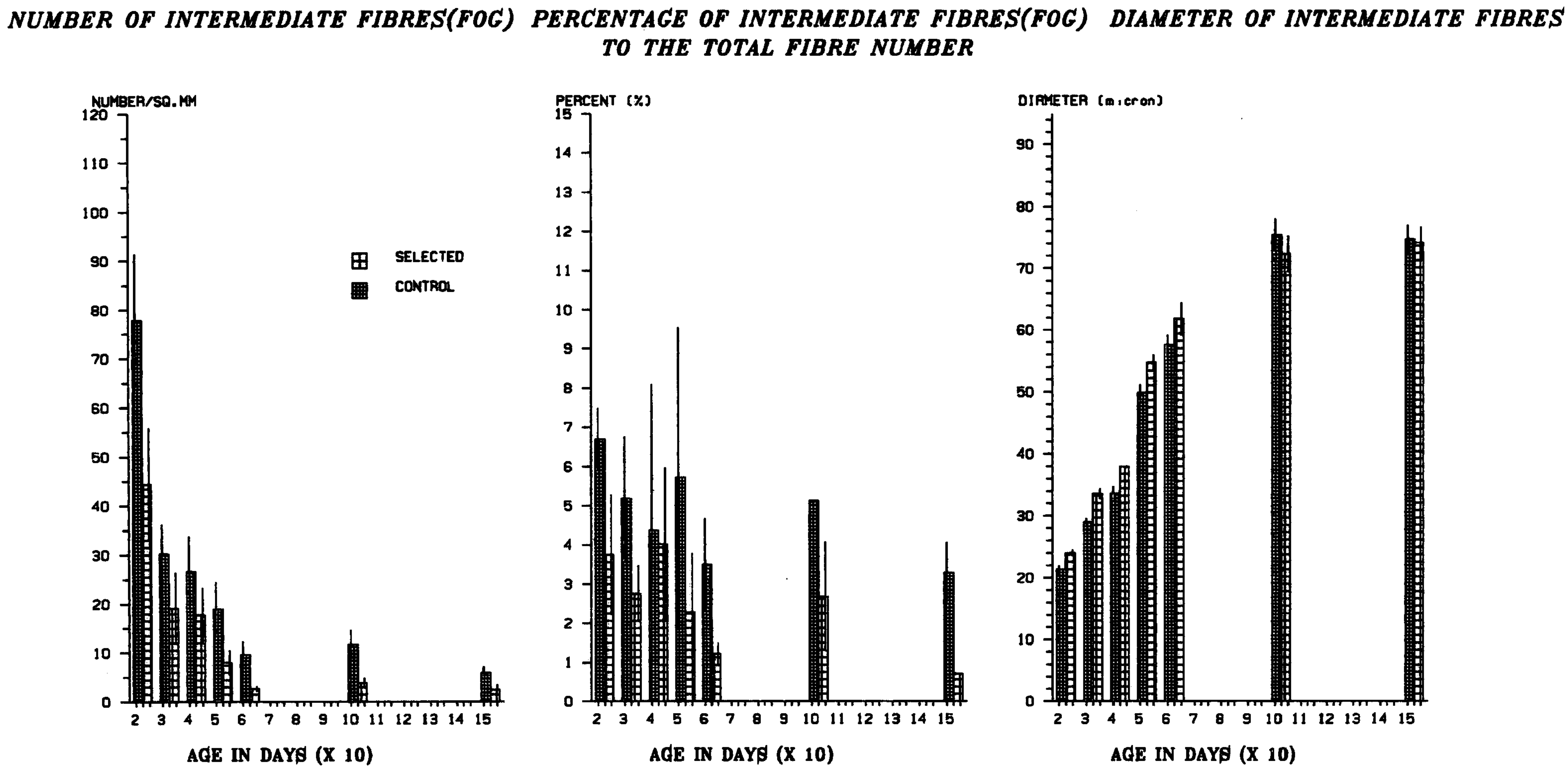


FIGURE 4.35 – INTERMEDIATE FIBRES(FOG) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

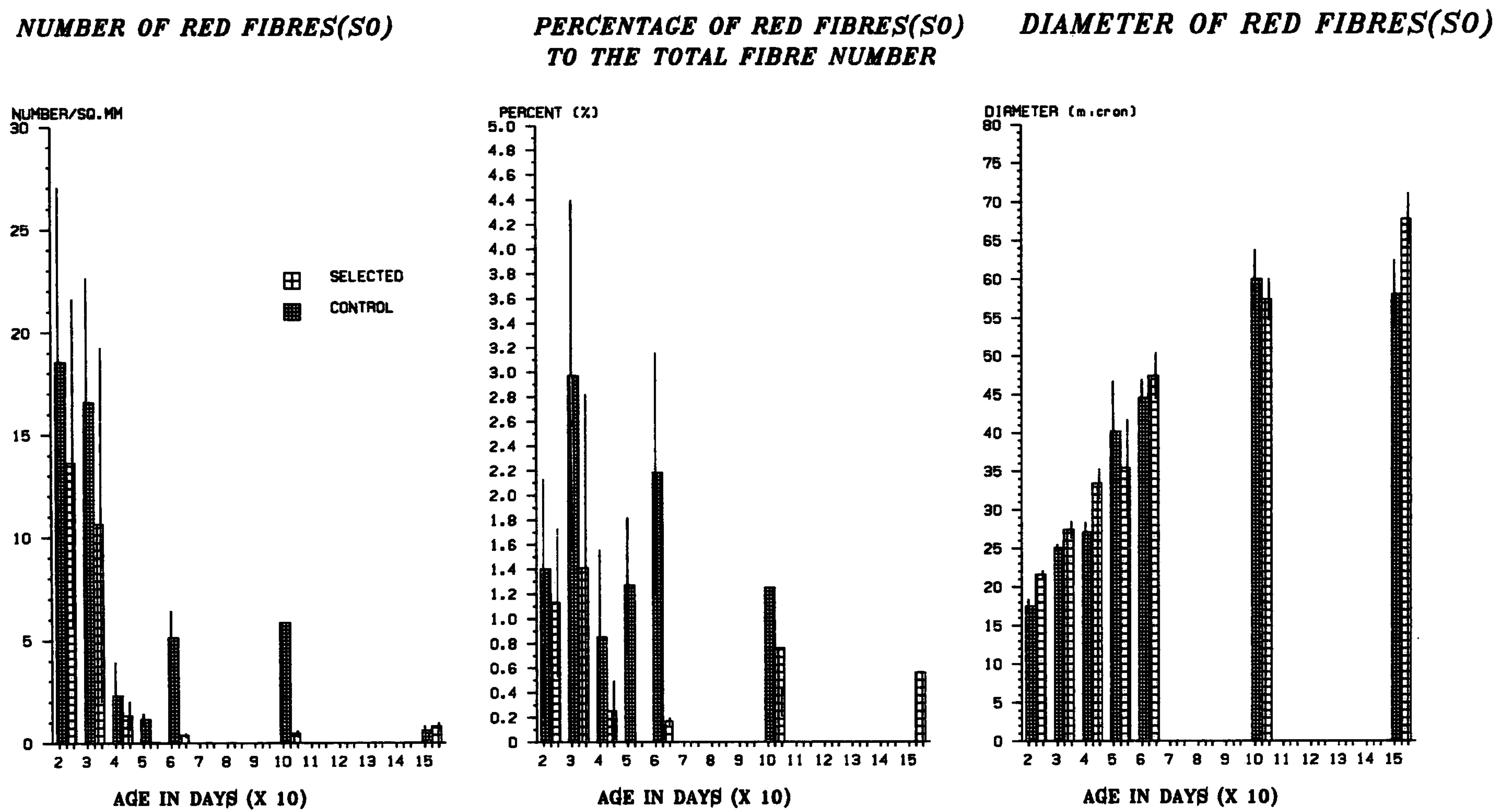


FIGURE 4.36 – RED FIBRES(SO) IN THE RIGHT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

Table 4.10 — Result of t-test on the Average Number and Diameter of Fibre Types Between the Left Regions A and B in Control and their Corresponding ~~Right~~ Left Regions in Selected Chickens

Age (days)	No. of Birds C/S	Region	Fibre Type No./mm^2			Total No./mm^2	Fibre Type Diameter μm		
			Red(SO)	Inter.(FOG)	White(FG)		Red(SO)	Inter.(FOG)	White(FG)
20	3/3	A	N.S.	N.S.	N.S.	2.823^{**s}	2.496^{*c}	N.S.	7.722^{***c}
		B	2.932^{*c}	3.433^{**c}	N.S.	N.S.	N.S.	N.S.	4.377^{***c}
30	3/2	A	N.S.	N.S.	N.S.	N.S.	3.630^{***s}	4.963^{***s}	N.S.
		B	N.S.	N.S.	N.S.	N.S.	6.038^{***s}	8.618^{***s}	N.S.
40	3/3	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
50	3/3	A	N.S.	N.S.	N.S.	N.S.	8.422^{***s}	3.157^{**s}	5.536^{***s}
		B	–	N.S.	N.S.	N.S.	–	2.138^{*s}	2.209^{*s}
60	3/3	A	N.S.	N.S.	5.574^{***c}	4.354^{**c}	3.557^{***s}	4.027^{***s}	4.641^{***s}
		B	4.690^{***c}	3.201^{**c}	3.749^{***c}	4.331^{***c}	2.721^{**s}	1.992^{*s}	4.408^{***s}
100	1/3	A	2.449^{*c}	N.S.	10.099^{***c}	15.568^{***c}	5.437^{***s}	4.987^{***s}	11.079^{***s}
		B	N.S.	8.769^{***c}	8.470^{***c}	10.040^{***c}	N.S.	2.339^{*s}	3.010^{**s}
150	2/1	A	N.S.	N.S.	2.014^{*c}	5.329^{***c}	7.245^{***s}	N.S.	2.912^{**s}
		B	–	N.S.	2.514^{*c}	3.090^{**c}	–	2.797^{**s}	N.S.

Number of asterisks indicates degree of significance of the t-test. c or s indicates the control or selected chickens which is significantly larger in number or diameter of the fibre type.

4.5.2.1 Total Fibres Number

Control Chickens had very significantly larger total fibres number per square millimeter in both regions A and B, in old birds (60 to 150 days) than in selected chickens as shown in figures 4.37 and 4.38 respectively. With exception of the left region A at age 20 days only when selected chickens had significantly larger total fibre number than in controls as shown in figure 4.37.

FIGURE 4.37 – TOTAL FIBRE NUMBER IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

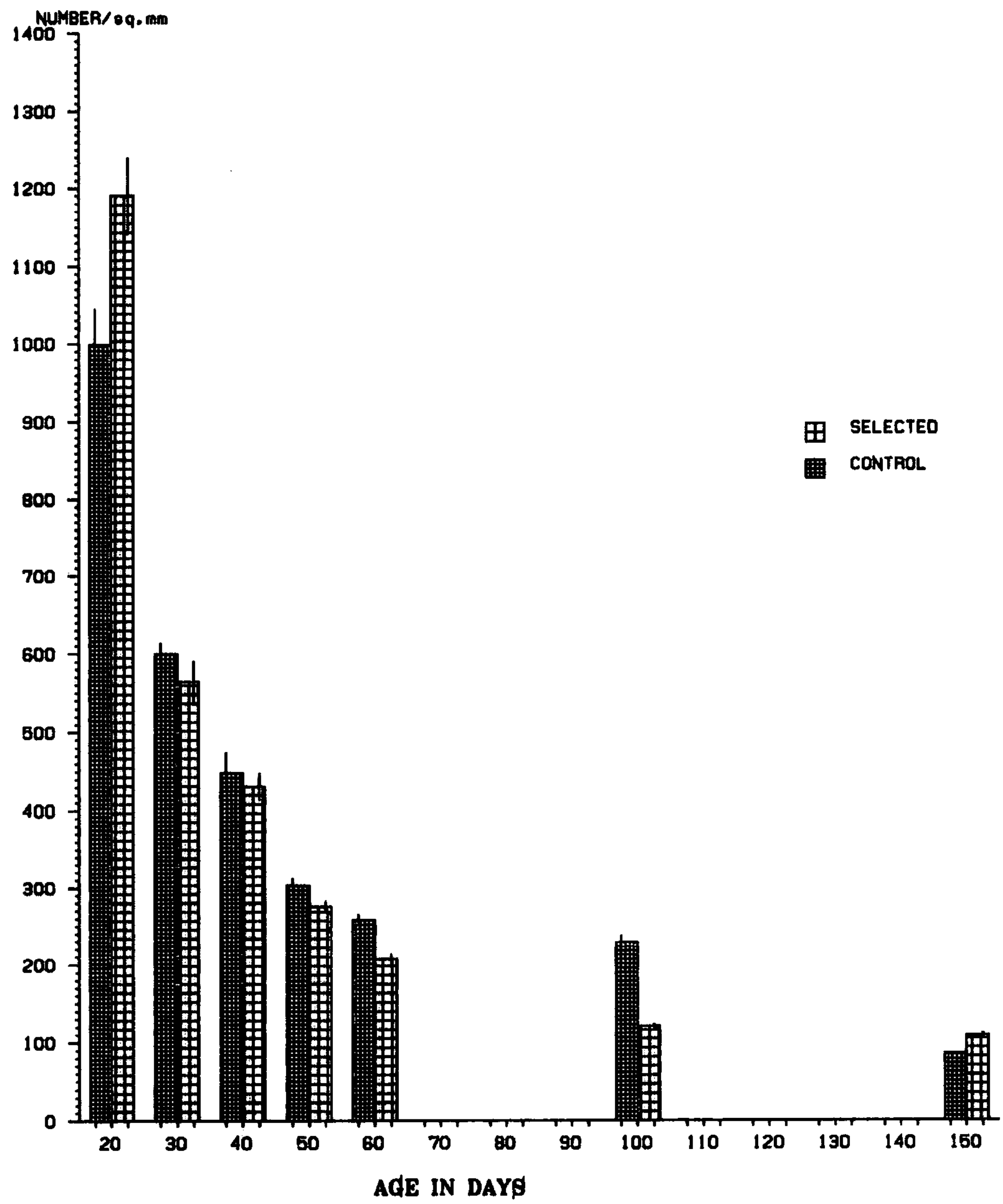
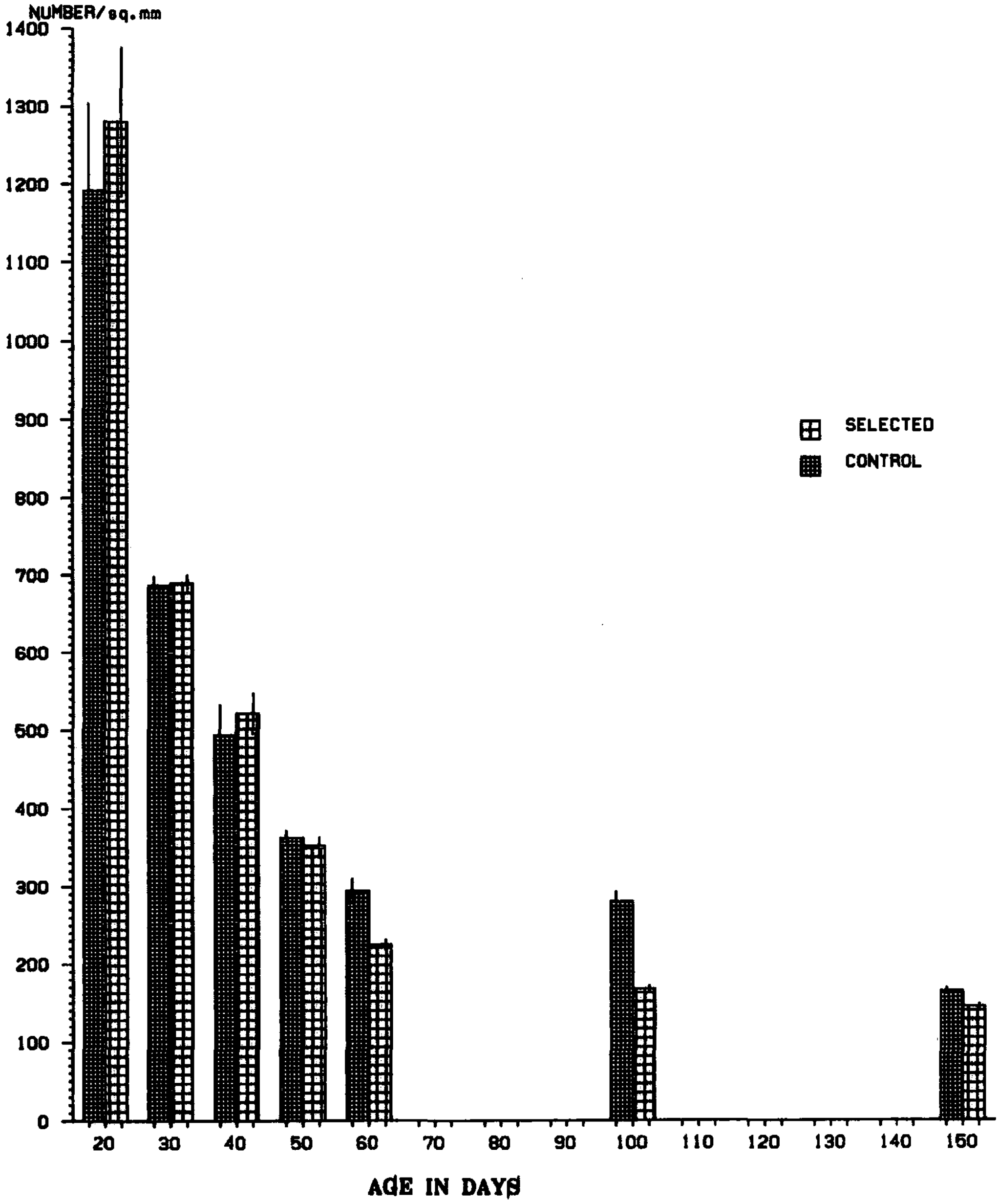


FIGURE 4.38 – TOTAL FIBRE NUMBER IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)



4.5.2.2 Fibre-Type Number

- Region A

White fibre number per square millimeter is the main difference of fibre-type number in the left region A between the control and selected chickens. Table 4.10 shows that white fibre number per square millimeter was very significantly larger in the control than in selected chickens at late age (60 to 150 days) as shown in figure 4.39, whereas intermediate- and red-fibre number per square millimeter were not significantly different as shown in figures 4.40 and 4.41 respectively and table 4.10.

- Region B

A similar result to white fibres in region A could be concluded that the number of white fibres per square millimeter was significantly larger in control than in selected chickens in old birds (60 to 150 days) as shown in table 4.10 and figure 4.42. Some significant differences were revealed at age 20, 60, and 100 days for intermediate and red fibres number when control chickens had significantly larger number per square millimeter as shown in figures 4.43 and 4.44 for intermediate and red fibres respectively.

4.5.2.3 Diameter of Muscle Fibres

Control chickens had significantly larger white- and red-fibre diameters at age 20 days only. Afterwards, the diameter of fibre types were significantly larger in selected birds than in control birds particularly in old birds, i.e. between 50 and 150 days of age, as shown in table 4.10, and figures 4.39-4.44.

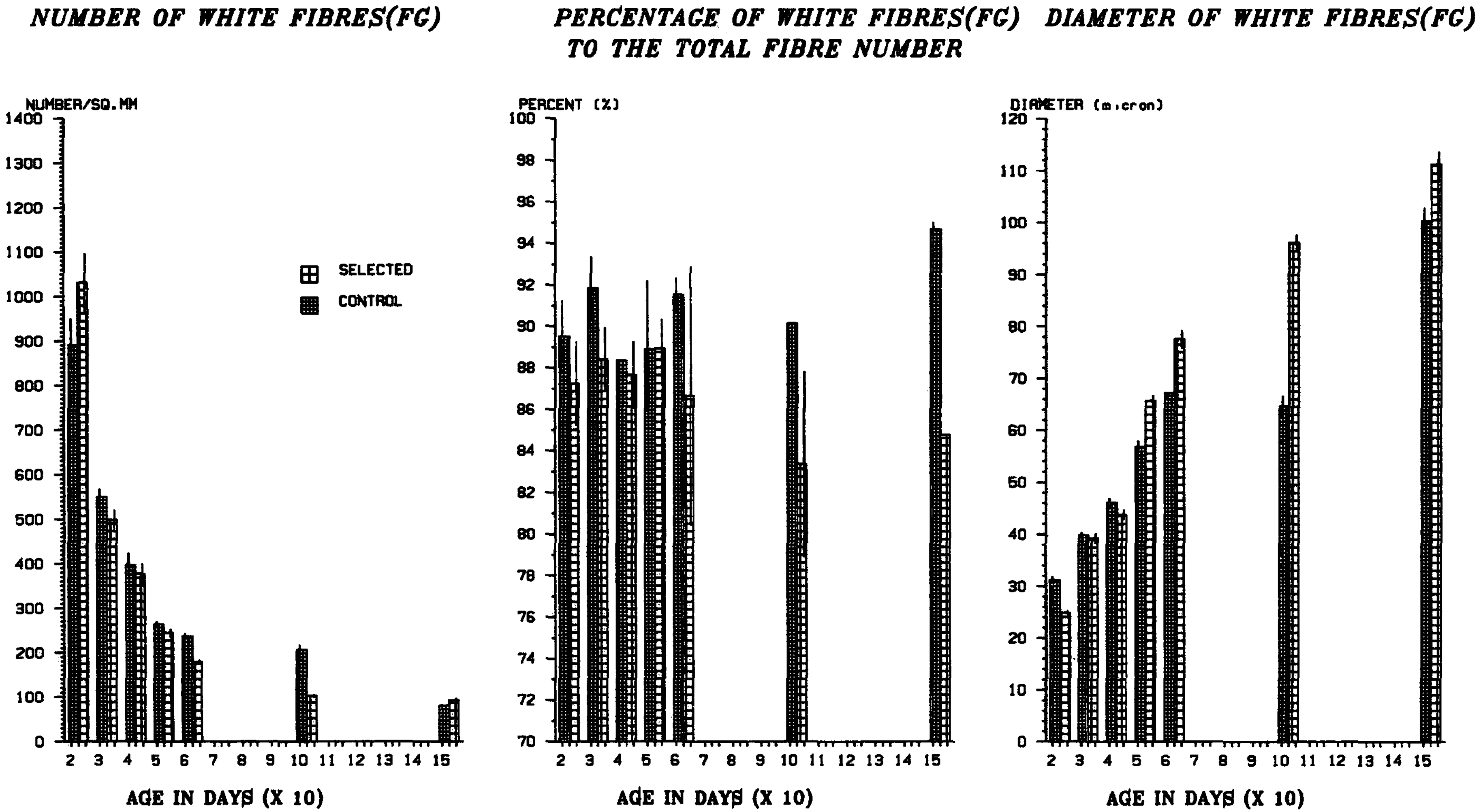


FIGURE 4.39 – WHITE FIBRES(FG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

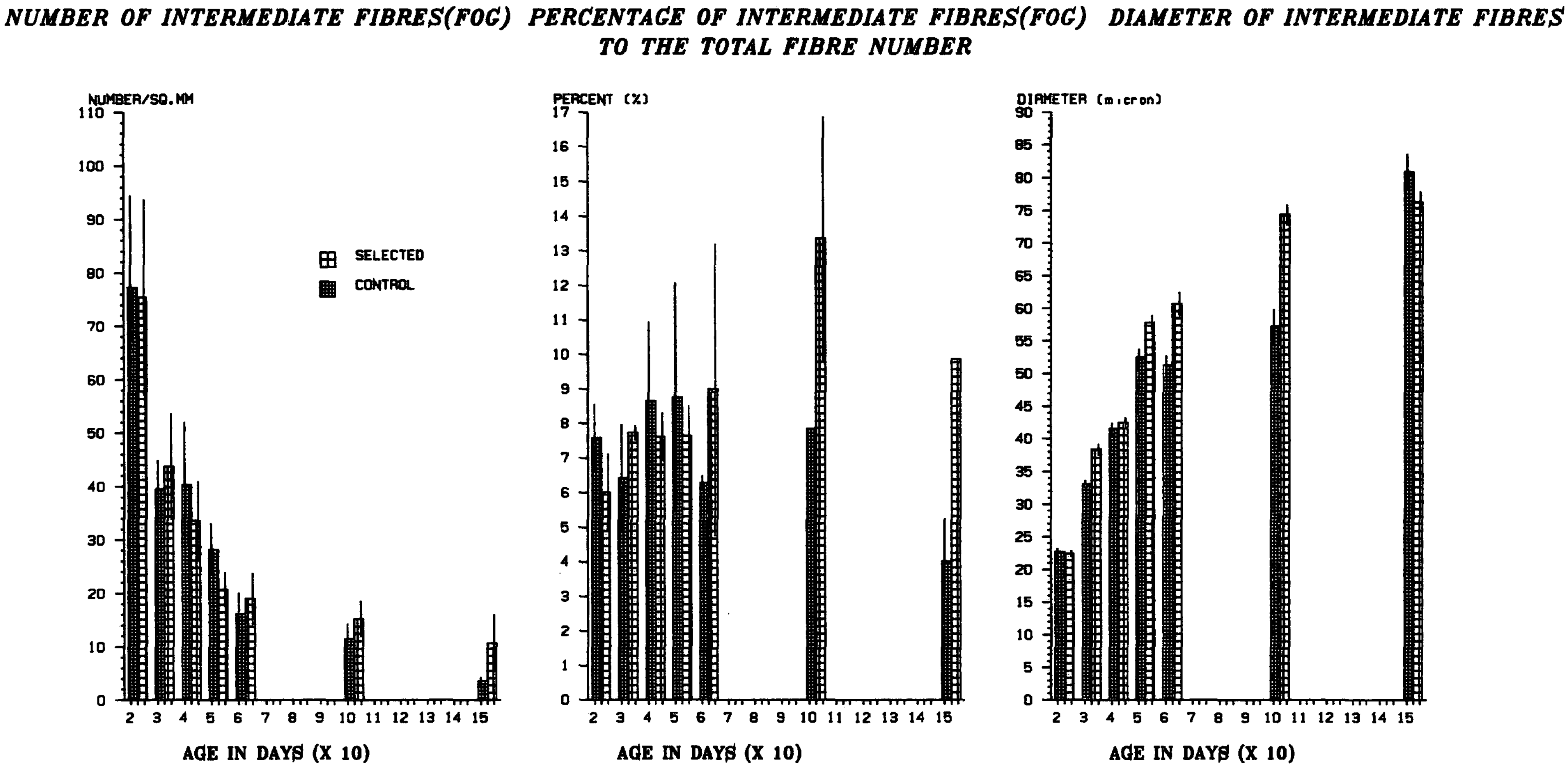


FIGURE 4.40 – INTERMEDIATE FIBRES(FOG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVERALL MEAN WITH STANDARD ERROR)

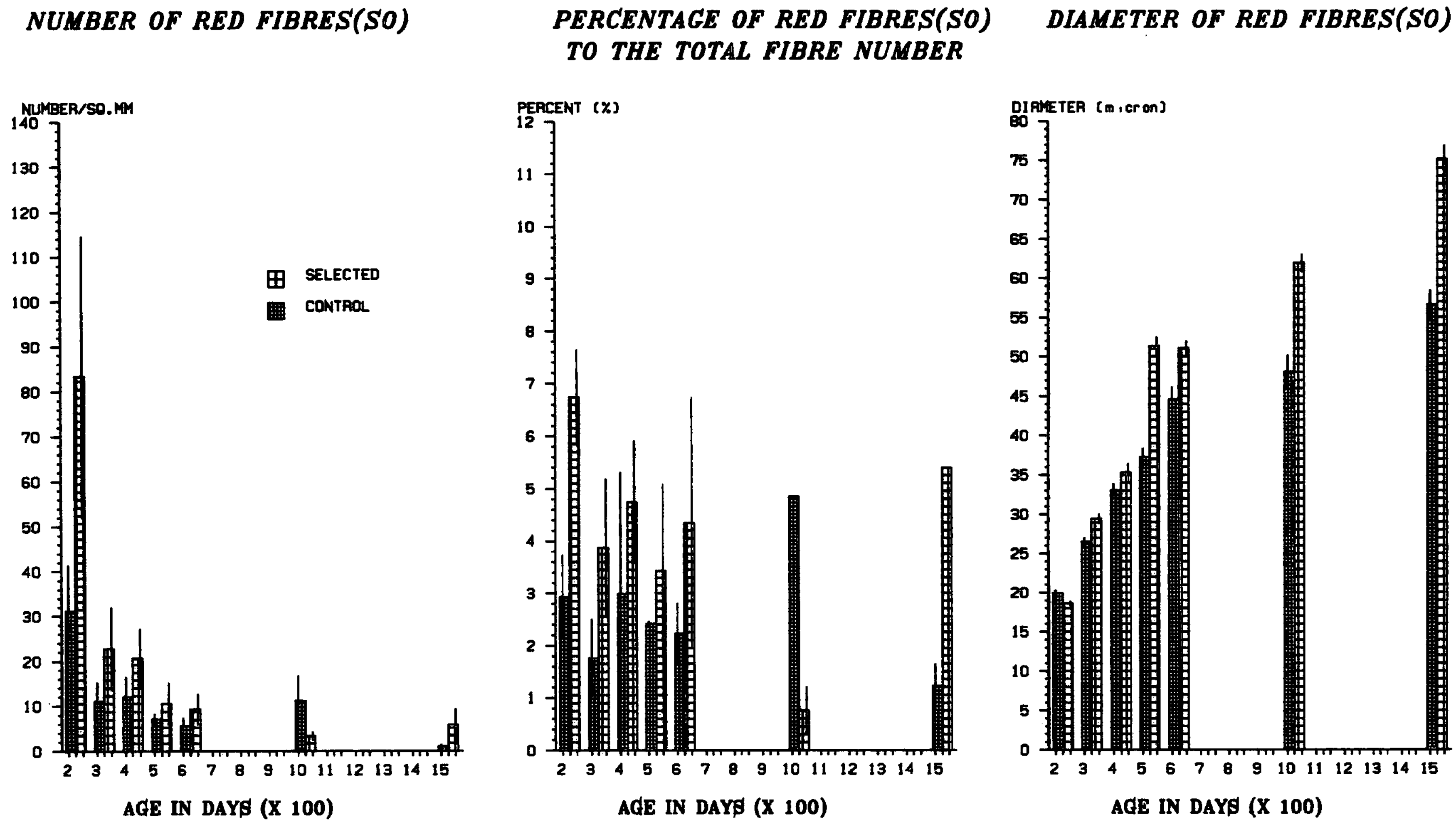


FIGURE 4.41 – RED FIBRES(SO) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION A)

(OVEALL MEAN WITH STANDARD ERROR)

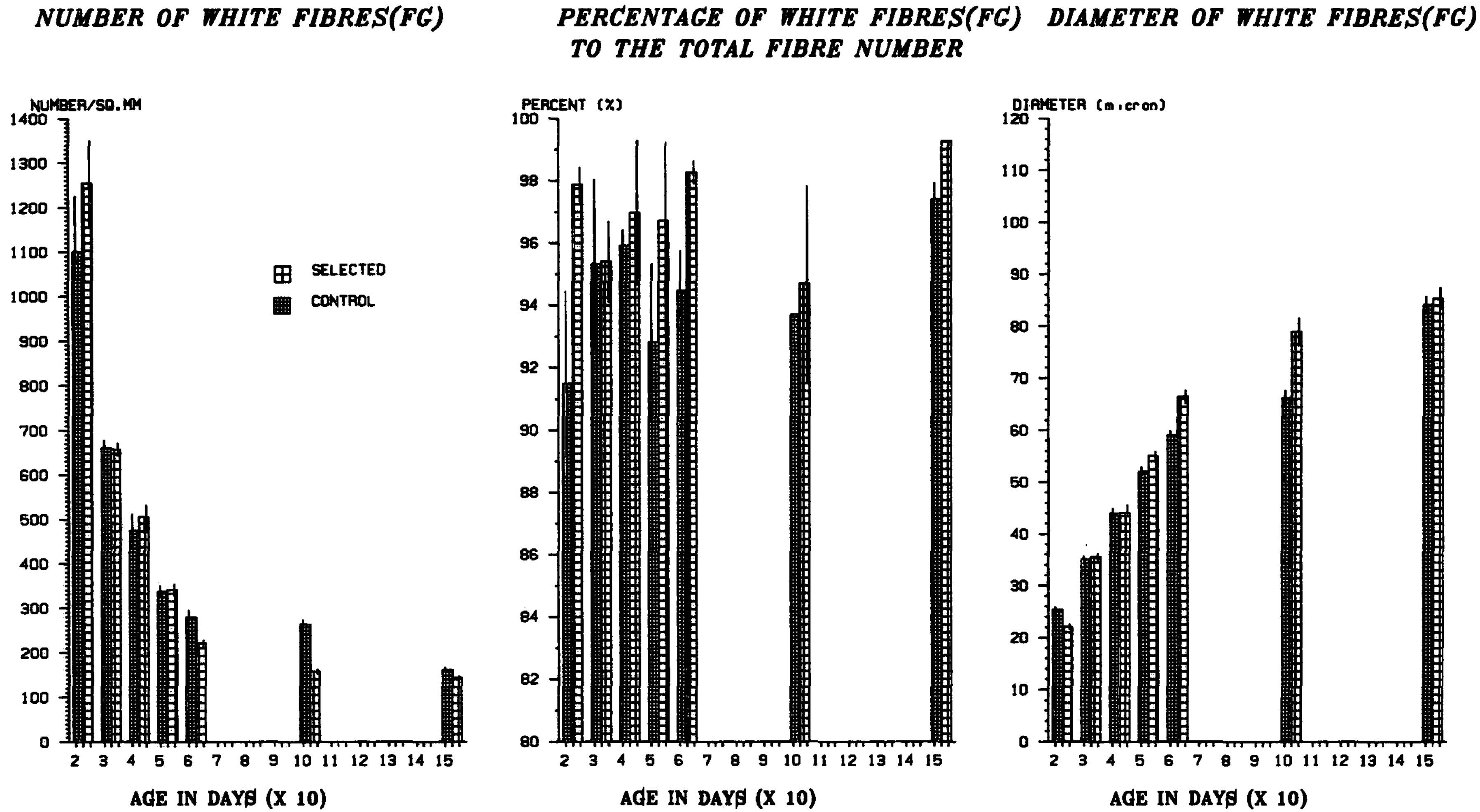


FIGURE 4.42 WHITE FIBRES(FG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

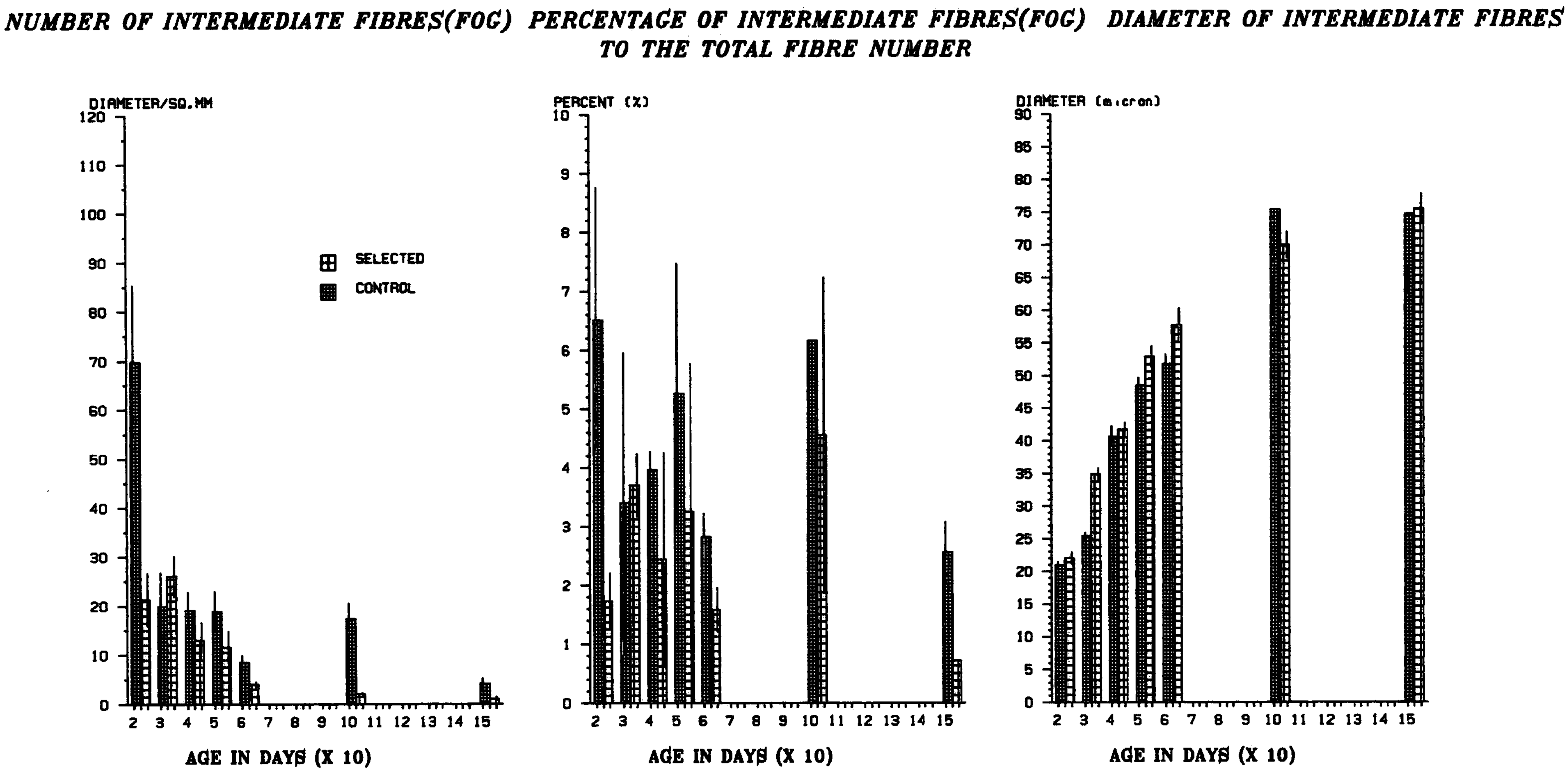


FIGURE 4.43 – INTERMEDIATE FIBRES(FOG) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

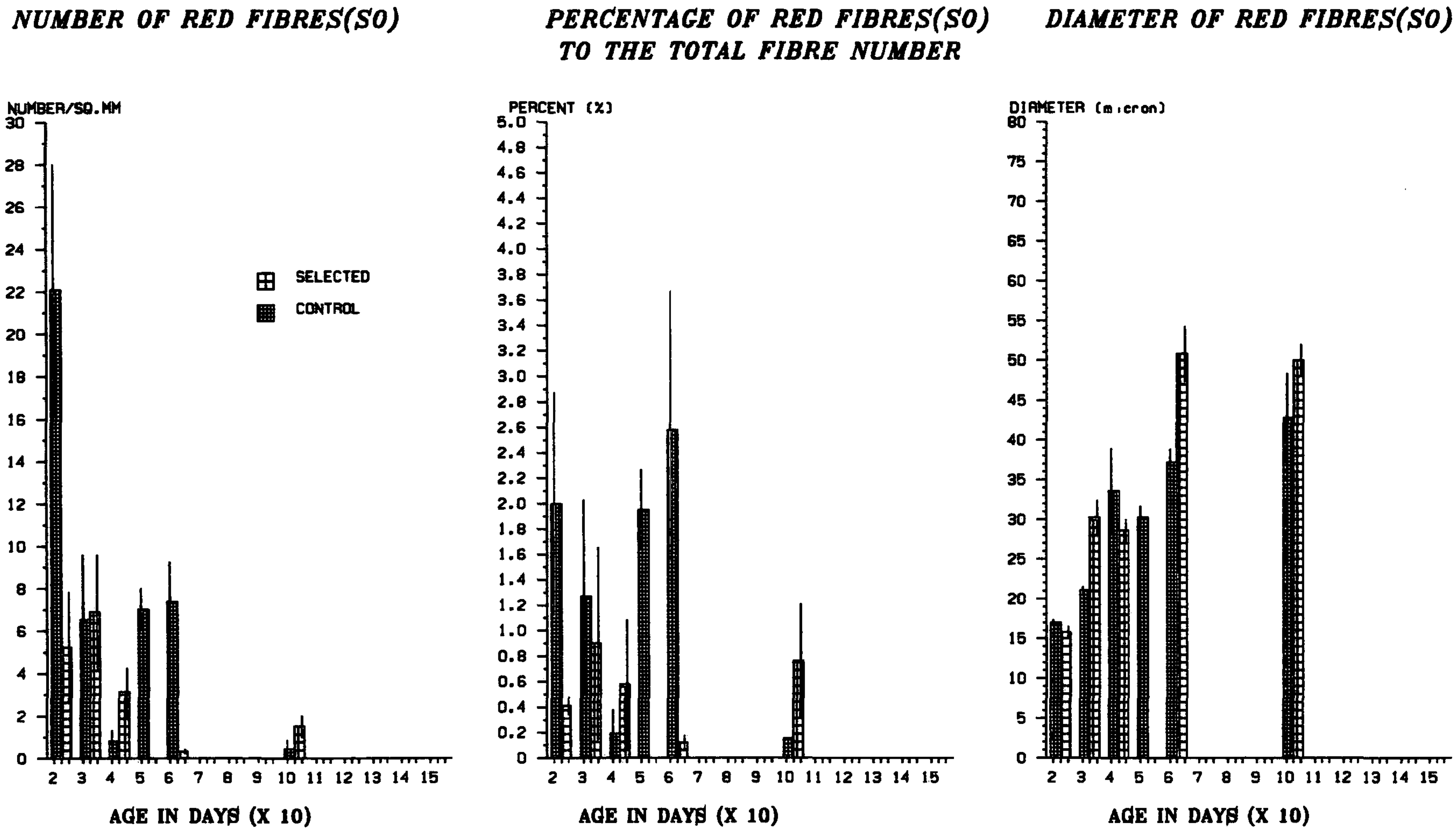


FIGURE 4.44 – RED FIBRES(SO) IN THE LEFT PECTORALIS MUSCLE IN CONTROL AND SELECTED CHICKENS (REGION B)

(OVERALL MEAN WITH STANDARD ERROR)

4.6 Relative Growth of the Fibres

In order to assess more fully the growth pattern of the pectoralis muscle, the relationship between growth in fibre number and diameter and both live body weight and pectoralis muscle weight was studied.

Log-transformed regression statistics of the number and diameter of fibre types versus live body weight and muscle weight were studied between 20 to 60 days post hatching, following a similar method to that used in the previous chapter (III).

4.6.1 Relative Growth of Fibre Number to Body Weight

Result of the regression analysis of the number of fibres against live body weight are presented in tables 4.11 and 4.12 for the control and selected chickens respectively. Student's *t*-test and *F*-test results of the growth coefficient of the number of fibres are presented in table 4.13.

4.6.1.1 Region A

Fibre number per square millimeter decreased substantially with muscle weight growth, and the allometric coefficient of fibre number was significantly different from zero in both control and selected chickens. In addition, the *t*-test was carried out on the allometric growth coefficient of the fibre number on the live body weight and muscle weight by subtracting theoretical isometrical value (0.667) from the slope value and then dividing the value by the standard error. Degree of freedom was (n−2) (see chapter II). In the control chickens the difference in allometric growth coefficient was not significant as shown in table 4.11, whereas in the selected chickens the allometric growth coefficient of the white-fibre number and the total fibre number was significantly different from 0.667 in the left region A as shown in table 4.12. Allometric growth coefficient in the right and left side was not significantly different in the control or selected chickens. *T*-test and *F*-test were carried out to compare the allometric growth coefficient of fibre number in the control and selected chickens; the result is given in table 4.13. The allometric growth coefficient of red and intermediate-fibres in both control and selected chickens were not significantly different, whereas white-fibre number and total fibre number in LA region of selected chickens had significant differences from the control chickens. White fibres in the selected chickens had allometric growth coefficient ($b = -0.825$) for LA region which was significantly larger than the two allometric growth coefficients of the RA and LA region in the control chickens ($t = 3.29$, $p < 0.05$; $t = 2.60$ $p < 0.05$ respectively). Also the slope was not parallel to both slopes in control chickens ($F = 10.73$, $p < 0.05$; $F = 6.81$ $p < 0.05$) as shown in table 4.13. In addition to the above, total fibre number in LA region of the selected chickens had a significantly larger allometric growth coefficient ($b = -0.827$) than the control chickens ($t = 3.03$ $p < 0.05$), and this slope was not parallel or identical to the total fibre number in LA region of the control chickens ($F = 9.17$ $p < 0.05$) as shown in table 4.13.

Red and white-fibre number per square millimeter in the selected chickens in LA region were significantly fewer than in the control chickens, and their decrease in number was faster too. As a result, the total number of fibres per square millimeter was less in LA region in the selected chickens than in LA region in the control chickens.

Table 4.11 — Result of Regression Analysis of Fibre Number on Body Weight and Muscle Weight in Control Chickens 20-60 Days of Age

		Red (SO)			Intermediate (FOG)			White (FG)			Total		
	Region	a	b $\pm$ SE	R^2	a	b $\pm$ SE	R^2	a	b $\pm$ SE	R^2	a	b $\pm$ SE	R^2
Body Weight	RA	3.529	-0.761 ± 0.051	0.987	4.053	-0.801 ± 0.106	0.950	4.719	-0.676 ± 0.029	0.995	4.792	-0.679 ± 0.065	0.974
	LA	3.520	-0.788 ± 0.142	0.911	3.685	-0.679 ± 0.134	0.896	4.759	-0.681 ± 0.042	0.989	4.803	-0.680 ± 0.035	0.992
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
	RB	4.277	-1.131 ± 0.597	0.544	4.328	-0.928 ± 0.135	0.941	4.930	-0.721 ± 0.079	0.965	5.015	-0.736 ± 0.074	0.970
	LB	2.731	-0.629 ± 0.802	0.170	4.085	-0.878 ± 0.211	0.852	4.862	-0.687 ± 0.021	0.997	4.910	-0.694 ± 0.014	0.999
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
Muscle Weight	RA	2.316	-0.637 ± 0.046	0.985	2.786	-0.676 ± 0.074	0.965	3.642	-0.565 ± 0.028	0.993	3.718	-0.572 ± 0.038	0.987
	LA	2.264	-0.654 ± 0.109	0.985	2.610	-0.568 ± 0.097	0.920	3.666	-0.563 ± 0.033	0.990	3.714	-0.563 ± 0.022	0.996
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
	RB	2.408	-0.909 ± 0.523	0.502	2.864	-0.784 ± 0.096	0.957	3.802	-0.610 ± 0.044	0.985	3.854	-0.622 ± 0.039	0.988
	LB	1.618	-0.463 ± 0.676	0.135	2.681	-0.727 ± 0.171	0.857	3.760	-0.567 ± 0.014	0.998	3.796	-0.573 ± 0.012	0.999
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–

† t-test to determine whether there is difference between the slopes of the right and left

Table 4.12 — Result of Regression Analysis of Fibre Number on Body Weight and Muscle Weight in Selected Chickens 20-60 Days of Age

		Red (SO)			Intermediate (FOG)			White (FG)			Total		
	Region	a	b ± SE ¶	R^2	a	b ± SE	R^2	a	b ± SE	R^2	a	b ± SE	R^2
Body Weight	RA	3.899	−0.762 ± 0.163	0.879	3.773	−0.706 ± 0.140	0.895	5.020	−0.776 ± 0.051	0.987	5.073	−0.769 ± 0.052	0.987
	LA	4.593	−1.042 ± 0.129	0.956	3.700	−0.691 ± 0.021	0.997	5.179	−0.825* ± 0.035	0.995	5.243	−0.827* ± 0.033	0.995
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
	RB	5.969	−1.780 ± 0.393	0.872	4.944	−1.222 ± 0.251	0.888	4.927	−0.710 ± 0.049	0.986	5.000	−0.729 ± 0.051	0.985
	LB	4.570	−1.355 ± 0.440	0.759	3.391	−0.727 ± 0.298	0.665	5.208	−0.798 ± 0.062	0.982	5.225	−0.799 ± 0.065	0.981
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
Muscle Weight	RA	2.639	−0.615 ± 0.145	0.857	2.606	−0.572 ± 0.124	0.876	3.747	−0.633 ± 0.050	0.981	3.809	−0.627 ± 0.054	0.978
	LA	2.896	−0.846 ± 0.133	0.931	2.587	−0.567 ± 0.028	0.993	3.849	−0.677 ± 0.042	0.989	3.909	−0.678 ± 0.043	0.988
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–
	RB	3.106	−1.484 ± 0.278	0.905	2.952	−1.005 ± 0.198	0.895	3.766	−0.582 ± 0.037	0.988	3.810	−0.597 ± 0.038	0.988
	LB	2.435	−1.138 ± 0.338	0.791	2.254	−0.616 ± 0.230	0.705	3.923	−0.656 ± 0.053	0.981	3.940	−0.658 ± 0.053	0.981
	t-test	–	N.S.	–	–	N.S.	–	–	N.S.	–	–	N.S.	–

¶ Number of asterisks indicate Growth coefficient different from 0.667 at 0.05(*), 0.01(**), 0.001(***) level.

† t-test to determine whether there is difference between the slopes of the right and left

Table 4.13 — Result of t-test and F-test of the Growth Coefficient of Fibre Number Between Control vs. Selected Chickens Between 20-60 Days of Age

			Red (SO)				Intermediate (FOG)				White (FG)				Total			
	test	Region	RA	LA	RB	LB	RA	LA	RB	LB	RA	LA	RB	LB	RA	LA	RB	LB
Body Weight	t-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	3.29*	–	–	N.S.	N.S.	–	–
	F-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S	10.73*	–	–	N.S.	N.S.	–	–
	t-test	LA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	2.60*	–	–	N.S.	3.03*	–	–
	F-test	LA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	6.81*	–	–	N.S.	9.17*	–	–
	t-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	t-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
Muscle Weight	t-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	3.12*	3.29*	–	–	N.S.	N.S.	–	–
	F-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S	N.S.	–	–	N.S.	N.S.	–	–
	t-test	LA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	2.38*	–	–
	F-test	LA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–
	t-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	t-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.

t-test to determine whether there is difference between the slopes of the two data or not.

F-test to determine whether there is difference between the linear regression of the two data or not.

4.6.1.2 Region B

In region B, the numbers of all fibre types had allometric growth coefficient significantly different from zero in both control and selected chickens, but they were not significantly different from 0.667 as shown in tables 4.11 and 4.12 respectively. There was no significant difference between the regions, within or between the control and selected chickens.

Table 4.14 — Result of Regression Analysis of Fibre Diameter on Body Weight, and Muscle Weight in Control Chickens 20-60 Days of Age

		Red (SO)			Intermediate (FOG)			White (FG)		
	Region	a	b ± SE	R^2	a	b ± SE	R^2	a	b ± SE	R^2
Body Weight	RA	0.411	0.353 ± 0.054	0.935	0.399	0.386 ± 0.051	0.950	0.422	0.397 ± 0.033	0.980
	LA	0.392	0.392 ± 0.019	0.997	0.227	0.432 ± 0.044	0.969	0.492	0.374 ± 0.032	0.979
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
	RB	0.010	0.463 ± 0.061	0.950	−0.007	0.497 ± 0.062	0.955	0.189	0.459 ± 0.053	0.962
	LB	0.179	0.397 ± 0.076	0.901	−0.010	0.495 ± 0.064	0.953	0.292	0.421 ± 0.030	0.999
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
Muscle Weight	RA	0.977	0.293 ± 0.049	0.992	1.018	0.321 ± 0.048	0.938	1.052	0.333 ± 0.024	0.984
	LA	0.889	0.323 ± 0.013	0.995	0.923	0.355 ± 0.042	0.960	1.089	0.311 ± 0.018	0.990
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
	RB	0.740	0.342 ± 0.039	0.971	0.776	0.420 ± 0.039	0.987	0.913	0.388 ± 0.031	0.982
	LB	0.824	0.323 ± 0.070	0.875	0.790	0.406 ± 0.059	0.940	0.968	0.347 ± 0.011	0.997
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-

Number of asterisks indicate growth coefficient significantly from 0.333 at 0.05(*), 0.01(**), and 0.001(***) level.

t-test to determine whether there is difference between the slopes of the right and left

4.6.2 Relative Growth of Fibre Diameter to Body Weight

Result of the regression analysis of the diameter of fibre against live body weight are presented in tables 4.14 and 4.15 for the control and selected chickens respectively. Student's t-test and F-test results of the growth coefficient of the diameter of fibre are presented in table 4.16.

4.6.2.1 Region A

The differences between the allometric growth coefficients of fibre diameter

Table 4.15 — Result of Regression Analysis of Fibre Diameter on Body Weight, and Muscle Weight in Selected Chickens 20-60 Days of Age

		Red (SO)			Intermediate (FOG)			White (FG)		
	Region	a	b ± SE	R^2	a	b ± SE	R^2	a	b ± SE	R^2
Body Weight	RA	0.827	$0.480^{**} \pm 0.014$	0.994	0.243	0.447 ± 0.041	0.969	0.148	$0.487^{**} \pm 0.021$	0.995
	LA	−0.074	$0.514^{*} \pm 0.035$	0.986	0.106	$0.482^{*} \pm 0.044$	0.976	−0.049	$0.546^{**} \pm 0.029$	0.991
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
	RB	2.780	0.504 ± 1.064	0.070	0.146	$0.464^{*} \pm 0.026$	0.991	0.131	0.480 ± 0.055	0.963
	LB	2.303	0.361 ± 1.080	0.036	0.135	$0.465^{*} \pm 0.030$	0.988	−0.008	$0.518^{**} \pm 0.030$	0.990
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
Muscle Weight	RA	0.827	$0.392^{*} \pm 0.018$	0.994	0.940	0.364 ± 0.041	0.964	0.945	0.398 ± 0.021	0.992
	LA	0.977	0.420 ± 0.038	0.977	0.888	0.393 ± 0.048	0.957	0.832	$0.448^{*} \pm 0.033$	0.984
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-
	RB	1.927	0.398 ± 0.873	0.065	0.146	0.379 ± 0.023	0.991	0.909	0.395 ± 0.034	0.978
	LB	1.713	0.291 ± 1.080	0.035	0.887	0.381 ± 0.034	0.977	0.827	0.425 ± 0.031	0.984
	t-test	-	N.S.	-	-	N.S.	-	-	N.S.	-

Number of asterisks indicate growth coefficient significantly from 0.333 at 0.05(*), 0.01(**), and 0.001(***) level.

***t*-test to determine whether there is difference between the slopes of the right and left**

on the two sides of the pectoralis muscle were not significant either in control or selected chickens, as would be expected on the bases of the above results on fibre number. However, white and red-fibre diameters in the selected chickens had significantly larger allometric growth coefficient than in the control chickens. RA region in the selected chickens had larger allometric growth coefficient for white-fibres than both RA and LA regions in control chickens ($t = 2.33$, $p < 0.05$ and $t = 3.42$, $p < 0.05$ respectively), and the slopes were not parallel ($F = 11.69$, $p < 0.05$). On the other hand, LA region in the selected chickens had significantly

Table 4.16 — Result of *t*-test and *F*-test of the Growth Coefficient of Fibre Diameter Between Control vs. Selected Chickens 20–60 Days of Age

			Red (SO)				Intermediate (FOG)				White (FG)			
	test	Region	RA	LA	RB	LB	RA	LA	RB	LB	RA	LA	RB	LB
	t-test	RA	N.S.	2.51*	–	–	N.S.	N.S.	–	–	2.33*	3.42**	–	–
	F-test	RA	N.S.	6.36*	–	–	N.S.	N.S.	–	–	N.S	11.69*	–	–
	t-test	LA	3.76**	3.25*	–	–	N.S.	N.S.	–	–	2.98*	3.99 **	–	–
Body	F-test	LA	20.80**	10.32*	–	–	N.S.	N.S.	–	–	8.96*	24.51**	–	–
Weight	t-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	t-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	3.22*
	F-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	10.06*
	t-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	2.80*	–	–
	F-test	RA	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	7.68*	–	–
	t-test	LA	3.14*	2.44*	–	–	N.S.	N.S.	–	–	3.16*	3.62*	–	–
Muscle	F-test	LA	9.75*	N.S.	–	–	N.S.	N.S.	–	–	8.13*	12.88*	–	–
Weight	t-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	RB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	t-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.
	F-test	LB	–	–	N.S.	N.S.	–	–	N.S.	N.S.	–	–	N.S.	N.S.

t-test to determine whether there is difference between the slopes of the two data or not.

F-test to determine whether there is difference between the linear regression of the two data or not.

larger (b = 0.546) allometric growth coefficient than RA and LA regions in the control chickens ($t = 2.98$, $p < 0.05$ and $t = 3.99$, $p < 0.01$; respectively), and also the slope was significantly different too ($F = 8.96$, $p < 0.05$ and $F = 24.51$, $p < 0.01$), which means that the diameter of white-fibres in LA region of selected chickens was increasing faster than the white- fibres in both RA and LA regions in the control chickens.

Similarly, the diameter of the red-fibres in LA region in selected chickens was increasing faster than the red-fibres in the control chickens.

4.6.2.2 Region B

In region B, the diameter of all fibre types had similar allometric growth coefficient in the control and selected chickens, except LB region in the selected chickens where the diameter of white-fibre had high allometric growth coefficient ($b = 0.518$) significantly different ($t = 3.22$, $p < 0.05$) from LB region in control chickens, and the slope was also significantly different from the control chickens ($F = 10.06$, $p < 0.05$).

4.6.3 Relative Growth of Fibre Number to P. Muscle Weight

Growth and development of fibre number and diameter in pectoralis muscle was studied in relation to the body weight as presented above. The relationship between these fibre types and the pectoralis muscle weight itself was studied too in order to understand more fully the growth of the fibre types in relation to the pectoralis muscle weight and size.

Result of the regression analysis of the number of fibres against pectoralis muscle weight are presented in tables 4.11 and 4.12 for the control and selected chickens respectively. Student's t-test and F-test results of the growth coefficient of the number of fibres are presented in table 4.13.

4.6.3.1 Region A

Allometric growth coefficient of all fibre types were significantly different from zero for both control and selected chickens. However no significant differences were obtained from 0.667 in both the control and selected chickens as shown in tables 4.11 and 4.12. respectively. There was no significant difference in allometric growth coefficient between the two sides of the pectoralis muscle in control or selected chickens. However, table 4.16 presents the result of *t*-test and *F*-test of the comparison between the right and left side and region A and B of the control and selected chickens. The allometric growth coefficient of the total fibre number per square millimeter in LA region of the selected chickens ($b = -0.678$) was significantly higher in value ($t = 2.38$, $p < 0.05$) than its corresponding side in the control chickens. Thus fibre number in LA region of the selected chickens was decreasing in ratio to muscle growth weight more than in the control chickens.

4.6.3.2 Region B

There were no significant differences in the growth coefficient between the control and selected chickens of both sides.

4.6.4 Relative Growth of Fibre Diameter to P. Muscle Weight

Result of the regression analysis of the diameter of fibre against pectoralis muscle weight are presented in tables 4.13 and 4.14 for the control and selected chickens respectively. Student's *t*-test and *F*-test results of the growth coefficient of the diameter of fibre are presented in table 4.13.

4.6.4.1 Region A

Similarly, allometric growth coefficient of fibre diameter were significantly different from zero, but they were not different from 0.333 except the red-fibre diameter in the RA in the selected chickens. Also, there were no significant differences between the right and left side of pectoralis muscle in the control or selected chickens. In conformity with the rapid decrease in total fibre number per square millimeter in LA region of the selected chickens, white-fibre diameter in that region had a high allometric growth coefficient ($b = 0.448$) which was significantly larger than both RA and LA regions of the control chickens ($t = 2.80$, $p < 0.05$ and $t = 3.62$, $p < 0.05$ respectively). Also the slopes were different and not parallel ($F = 7.68$, $p < 0.05$ and $F = 12.88$, $p < 0.05$ respectively), which means that white-fibre diameter in LA region of the selected chickens was increasing faster in relation to the muscle weight than the two regions RA and LA of the control chickens. In addition to the white fibre, red fibres in the selected chickens also had significantly larger allometric growth coefficient in LA region than the control chickens.

4.6.4.2 Region B

A similar result could be derived from table 4.14 and 4.15, that the allometric growth coefficient of the fibre number was not significantly different from 0.667 in both the control and selected chickens. There were no significant differences in the growth coefficient between the control and selected chickens of both sides as shown in table 4.16.

CHAPTER V

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Chapter V

PECTORALIS MUSCLE ARCHITECTURE IN THE MOST ASYMMETRICAL SELECTED CHICKENS

5.1 Introduction

In the previous chapters (III and IV), selected chickens were studied anatomically and histochemically and compared to the control chickens. The mean asymmetry of the right pectoralis muscle, expressed as percentage by mass of the left in selected chickens (94.66%) was significantly larger than that for the control birds (96.90%), The difference is small ($< 3\%$) and it should be recalled that the selected and control birds were received at different ages and different times in Durham. Moreover, the total muscle-fibre number and the number of each fibre type (per square millimeter), were not significantly different between the right and left muscle in selected chickens (see chapter IV), though some significant differences between the two groups of chickens were found sporadically in the growth of the pectoralis muscle and the diameter of fibre types.

Since the pectoralis muscles of selected birds, as a population, were not very different from those of control birds, I decided to look particularly at a small number of birds showing the greatest of muscle-weight asymmetry. Before carrying out this study I visited the Cobb Breeding Company, particularly to assess the accuracy of the manual method of selection of "asymmetrical" birds. The results of that visit are described in chapter VI, but one consequence was that, subsequently, suspected asymmetry was confirmed using an ultrasonic probe (SCANCO

Table 5.1 — Live Body Weight, Muscle Weight, and Degree of Asymmetry in Chickens Selected by Ultrasonic Device at age 50 Days

Bird† No.	Body Weight (g)	Muscle Weight Right	Muscle Weight Left	Degree of Asymmetry R/L (%)
1	2160	108.08	119.14	90.72
2	1990	106.35	115.12	92.38
3	2250	115.97	126.75	91.50

†These birds were chosen from table 6.1, chapter VI as the most asymmetrical birds.

ULTRASONIC SCANOPROBE II, MODEL 731C). The asymmetrical birds to be described in this chapter were selected using the ultrasonic device, the data derived from them are compared to the data from control chickens at the same age (already described in chapter III).

Selected chickens aged 50 days were received from Cobb Breeding Company. This age was chosen as corresponding to the maximum growth rate of total body weight (see chapter III and figure 3.2). Some birds were killed immediately, the remainder reared until 100 days of age and then killed for more detailed study.

5.2 Live Body weight (LBW)

Sixteen and fourteen selected birds were dissected at ages 50 and 100 days respectively (see tables 6.1 and 6.2. Chapter VI), and the three at each age with the most asymmetrical pectoralis muscle weights were chosen for anatomical and histochemical analysis as shown in tables 5.1 and 5.2.

The mean live body weight of the selected and control chickens are given

Table 5.2 — Live Body Weight, Muscle Weight, and Dgree of Asymmetry in Chickens Selected by Ultrasonic Device at age 100 Days

Bird† No.	Body Weight (g)	Muscle Weight Right	Left	Degree of Asymmetry R/L (%)
1	6340	382.72	421.40	90.82
2	6350	448.29	482.18	92.97
3	5800	341.47	366.90	93.07

†These birds were chosen from table 6.1, chapter VI as the most asymmetrical birds.

in table 5.3, and plotted in figure 5.1. Control chickens had significantly heavier live body weight than the selected chickens at age 50 days ($t = 2.946$, $p < 0.05$) possibly the result of transferring the selected chickens from the Cobb Breeding Company to Durham at this age (control chickens had been reared at Durham from hatching date as described in Chapter II), whereas selected chickens had a significantly heavier live body weight than the control chickens at age 100 days ($t = 7.291$, $p < 0.01$). These differences, although statistically significant, are probably not of importance to the comparisons of muscle architecture.

5.3 Pectoralis Muscle

The following measurements were taken on each pectoralis muscle: total wet weight, percentile water, proportion of muscle wet weight to live body weight, and the relative size of the right and left muscles, expressed as the percentage by weight of the right to left muscle in selected birds. Data are given in table 5.3 and plotted in figure 5.2.

FIGURE 5.1 – LIVE BODY WEIGHT IN CONTROL AND THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES

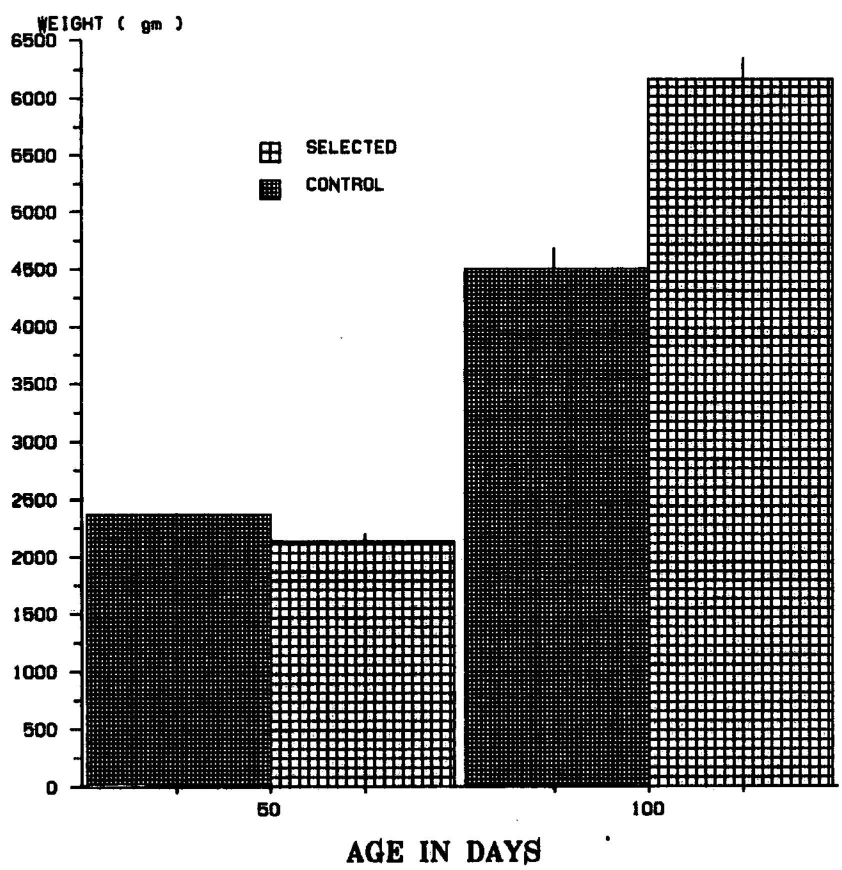


Table 5.3 — Live Body Weight, Pectoralis Muscle Weight, Percentile Water, Proportion of LBW and Relative Size of the Right to Left Pectoralis Muscle in Control and Most Asymmetrical Selected Chickens

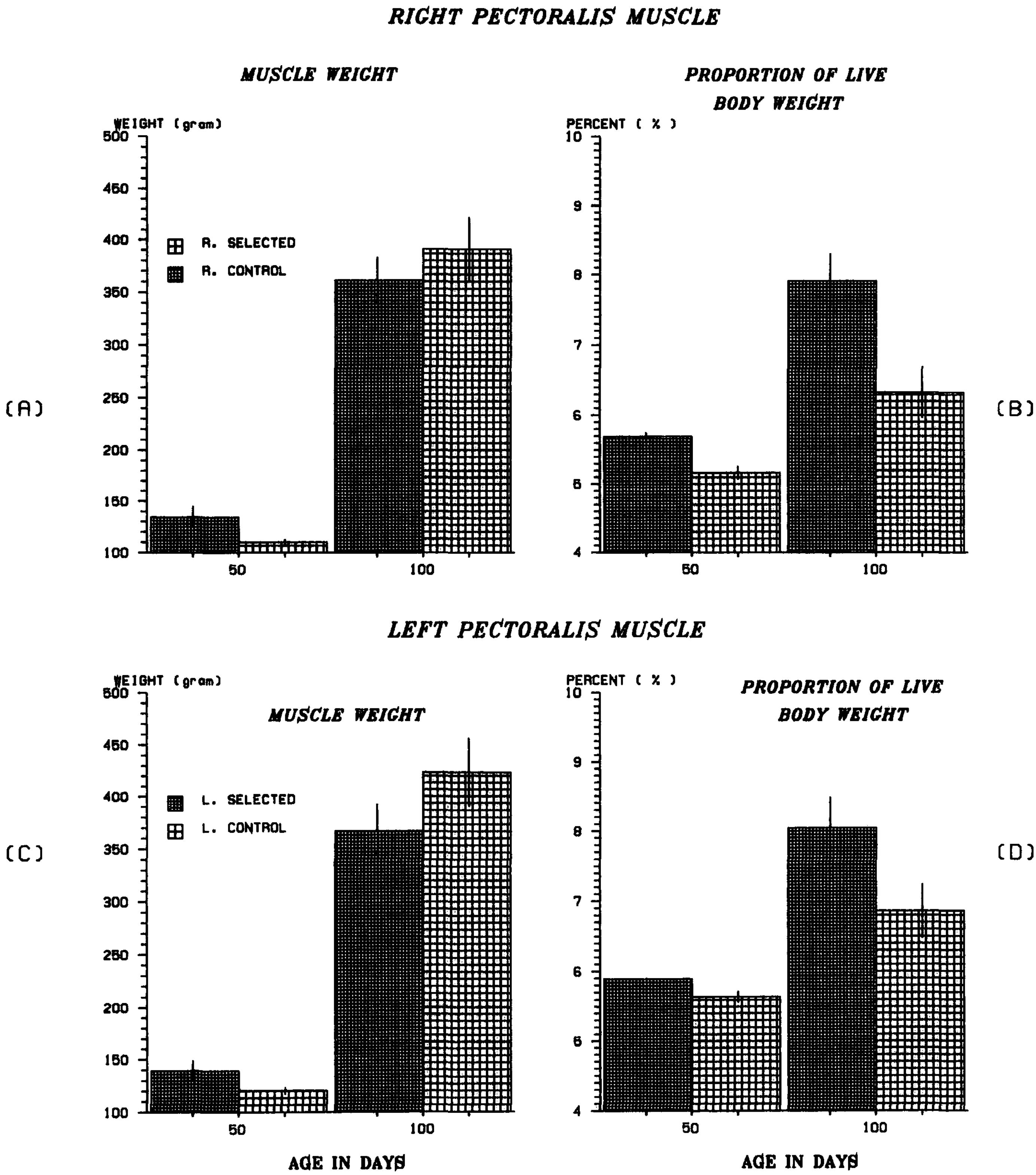
Mean ± SE given for each measurement

Age (Days)		50		100	
Group		Control	Selected	Control	Selected
Number of Birds		3	3	3	3
Body Weight (g)		2363.33 ± 16.810	2133.33 ± 76.231	4560.00 ± 124.900	6163.33 ± 181.690
Muscle Weight (g)	R	134.64 ± 10.198	110.13 ± 2.961	361.04 ± 21.990	390.83 ± 31.102
	L	139.09 ± 9.868	120.34 ± 3.410	367.17 ± 25.450	423.49 ± 33.295
Percentile Water (%)	R	–	73.34 ± 0.339	–	71.35 ± 0.277
	L	–	72.88 ± 0.422	–	71.08 ± 0.428
Proportion of Live Body Weight (%)	R	5.69 ± 0.064	5.17 ± 0.099	7.91 ± 0.391	6.33 ± 0.368
	L	5.88 ± 0.013	5.64 ± 0.078	8.042± 0.442	6.86 ± 0.380
Relative Size R/L (%)		96.73 ± 0.899	91.53 ± 0.481	98.46 ± 1.070	92.29 ± 0.734

5.3.1 Absolute Wet Weight of Pectoralis Muscle

No significant differences were obtained between the average weight of the right pectoralis muscles in the most asymmetrical selected chickens and the control chickens, nor in their left muscles, as shown in figures 5.2A and 5.2C (although there were significant differences in total body weight between the two groups of chickens).

FIGURE 5.2 – RIGHT AND LEFT PECTORALIS MUSCLE IN CONTROL AND THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES



5.3.2 Percentile Water

The weight of water in each pectoralis muscle of the selected chickens was estimated as the difference between the wet muscle weight and the dry weight (after drying in a vacuum oven). This weight of water was then expressed as a percentage of wet muscle weight and means presented in table 5.3. There were no significant differences between the right and left pectoralis muscle at either 50 or 100 days of age. However, percentile water decreased significantly with age in both the right and left sides of pectoralis muscle ($t=4.546$, $p < 0.05$ and $t=2.995$, $p < 0.05$ respectively).

5.3.3 Proportion of Pectoralis Muscle to LBW

Student's *t*-test revealed that the proportion contributed by the left pectoralis muscle to total body weight was significantly greater than the right one in control and selected chickens at age 50 days ($t = 2.909$, $p < 0.05$ and $t = 3.729$, $p < 0.05$ respectively), whereas the differences between the two proportions were not significant at age 100 days in either control or selected chickens (see tables 5.3). Comparisons between control and selected chickens are plotted in figures 5.2B and 5.2D. These figures show that the proportion contributed by the pectoralis muscle to total body weight in control chickens was significantly greater than in selected chickens at age 50 days in comparisons of the right side ($t = 4.411$, $p < 0.05$) and the left side (3.035, $p < 0.05$). At 100 days only the right pectoralis muscle in control chickens was significantly greater in proportion to total body weight than the corresponding muscle in selected chickens ($t = 2.946$, $p < 0.05$). The difference between the mean proportions contributed by the left muscles, although showing the same trends, was not statistically significant ($t = 2.028$, $p > 0.05$).

5.4 Pectoralis Muscle Architecture

The pectoralis muscle structure for the selected chickens was studied by using similar procedures of the histochemical methods used in chapter IV. These methods have been outlined in Chapter II: General Material and Methods.

The main purpose of the histochemical study on the most asymmetrical selected chickens was to reveal any asymmetrical structure in the two sides of the pectoralis muscle. Therefore, comparisons using Student's t-test were carried out between the two sides of the pectoralis muscle within each of the two regions A and B. (The comparison between regions A and B **within** a muscle was carried out in chapter IV with the very clear result that the two regions differed significantly in both control and selected chickens.)

5.4.1 Right Vs. Left Side of Pectoralis Muscle

The number and diameter of fibres in the right and left pectoralis muscle for both A and B regions in selected chickens are given for each of the three birds of ages 50 and 100 days in tables C.15 and C.16 in appendix C. The mean number and diameter of fibres of each age group are summarized in table 5.4.

5.4.1.1 Number of Fibres Per Square Millimeter

1. Total Fibre Number Per Square Millimeter

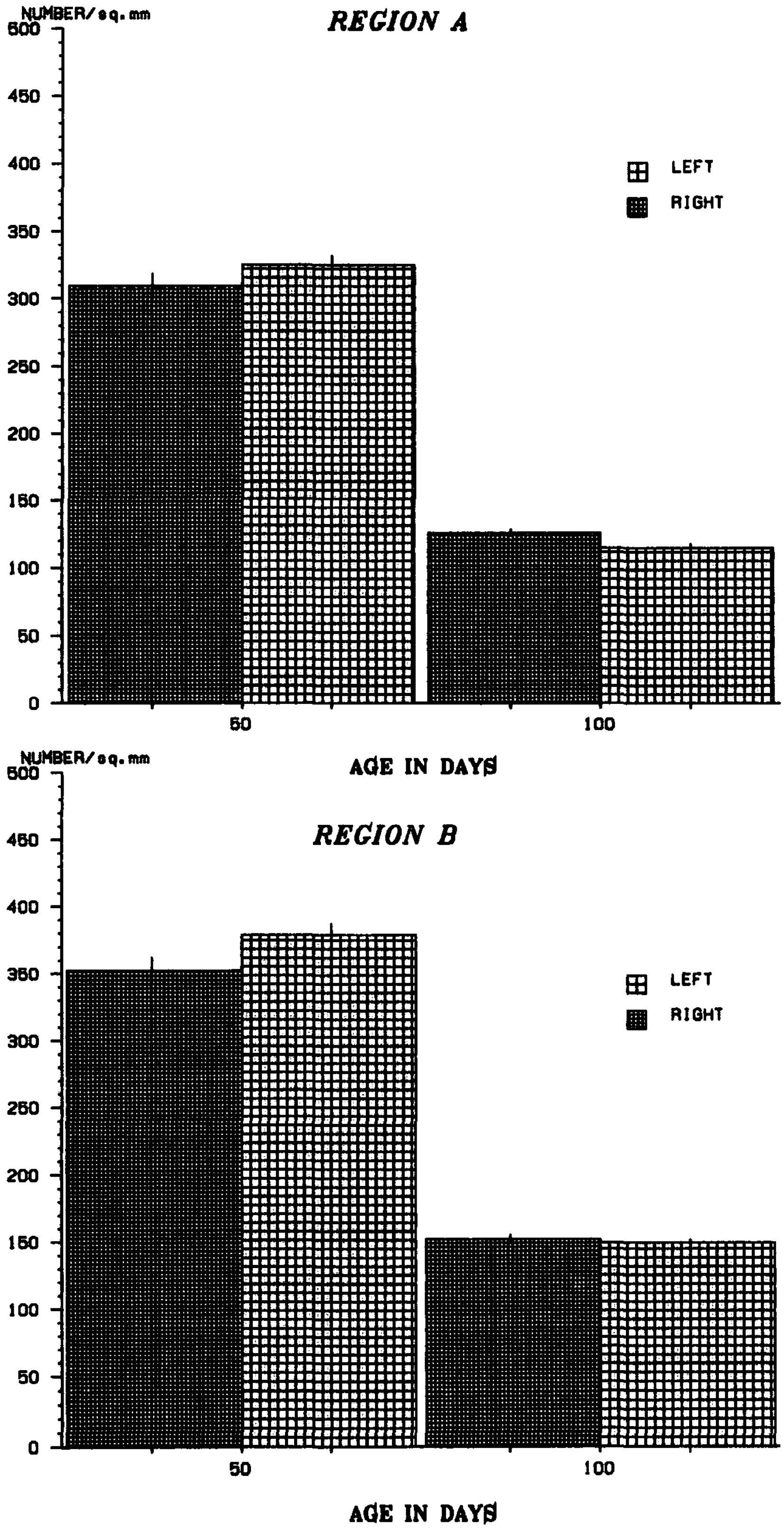
There were no significant differences in region A between the left and the right muscles at age 50 days, whereas at age 100 days, the total fibre number in region A of the right muscle was significantly larger ($t = 2.45$, $p < 0.05$) as shown in figure 5.3.

Table 5.4 - Average Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in the Most Asymetrical Selected Chickens

Age (Days)	No. of Birds	Body Weight (gram)	Muscle Weight (gram)	Region	Fibre Type No./mm^2			Total No./mm^2	Fibre Type Diameter μm		
					Red(SO)	Inter.(FOG)	White(FG)		Red(SO)	Inter.(FOG)	White(FG)
50	3	2133.33±76.23	R	A	4.14±1.98	21.19±5.31	283.96±12.66	309.29±9.33	51.16±1.04	56.76±0.87	63.96±1.08
			110.13±2.96	B	-	5.05±1.31	347.50±10.10	352.57±9.93	-	51.32±1.00	51.44±0.77
			L	A	6.17±2.03	28.96±6.72	290.31±9.42	325.44±7.22	46.80±1.03	50.13±0.49	61.29±0.94
			120.34±3.41	B	-	7.66±2.14	371.30±9.65	378.99±8.52	-	50.30±1.07	53.89±0.73
100	3	6163.33±181.69	R	A	5.12±1.90	8.30±1.66	112.77±2.51	126.15±2.94	62.59±0.96	72.96±0.93	93.26±1.34
			390.83±31.10	B	0.20±0.08	1.51±0.24	150.32±3.25	152.03±3.28	62.42±3.88	74.42±2.22	84.63±1.29
			L	A	9.34±3.06	7.64±1.71	97.79±3.06	114.79±3.56	65.23±1.08	74.98±0.53	91.33±1.18
			423.49±33.29	B	0.54±0.24	2.00±0.32	146.83±2.39	149.38±2.45	54.24±2.17	68.69±3.25	86.32±1.21

† Mean± SE

FIGURE 5.3 – TOTAL NUMBER OF MUSCLE FIBRE IN THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES



In region B, the total muscle-fibre numbers were not significantly different between the two sides at either age, as shown in figure 5.3.

2. White Fibres(FG)

The white-fibre number per square millimeter in region A was not significantly different between the right and left side of pectoralis muscle at age 50 days, whereas at age 100 days the right pectoralis muscle had a significantly larger ($t = 3.769$, $p < 0.001$) number than the left in region A as shown in figure 5.4. No significant differences were obtained in region B, as shown in figures 5.5.

3. Intermediate Fibres(FOG)

Intermediate-fibre number per square millimeter in region A was not significantly different between the two sides of the pectoralis muscle at age 50 and 100 days as shown in figure 5.6.

In region B, The two sides of the pectoralis muscle revealed no significant differences in the intermediate-fibre number as shown in figure 5.7.

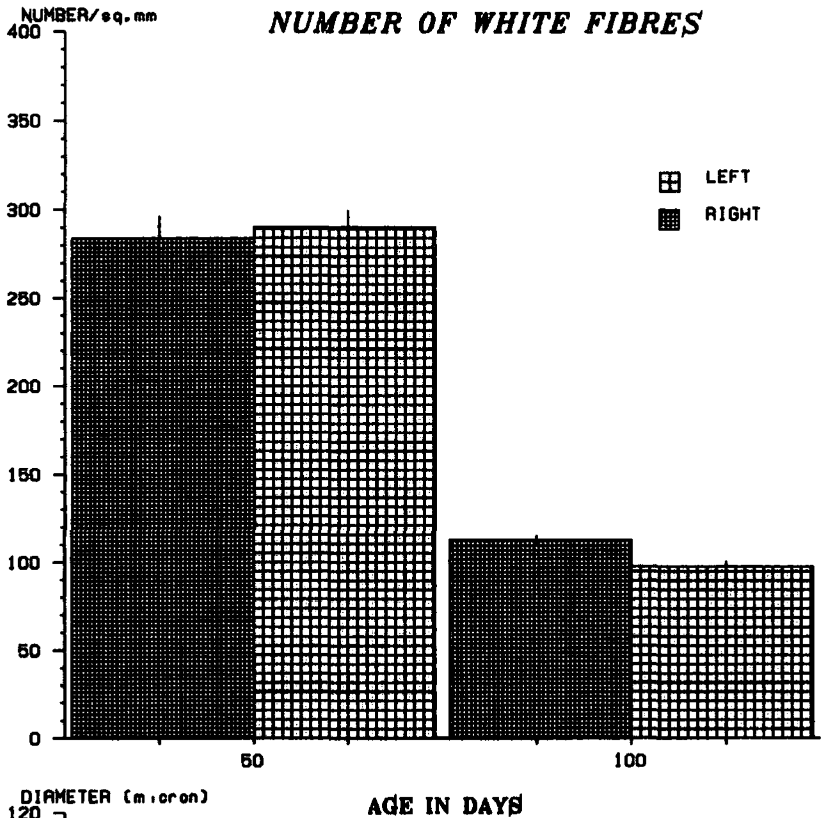
4. Red Fibres(SO)

There were no significant differences in red-fibre number between the two sides in both regions as shown in figures 5.8 and 5.9.

5.4.1.2 Diameter of Fibres

The mean diameter of each fibre type for each of the three birds at ages 50 and 100 days are given in tables C.15 and C.16 in appendix C. The average for each age group derived from these are presented in table 5.4.

FIGURE 5.4 – WHITE FIBRES(FG) IN THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION A)



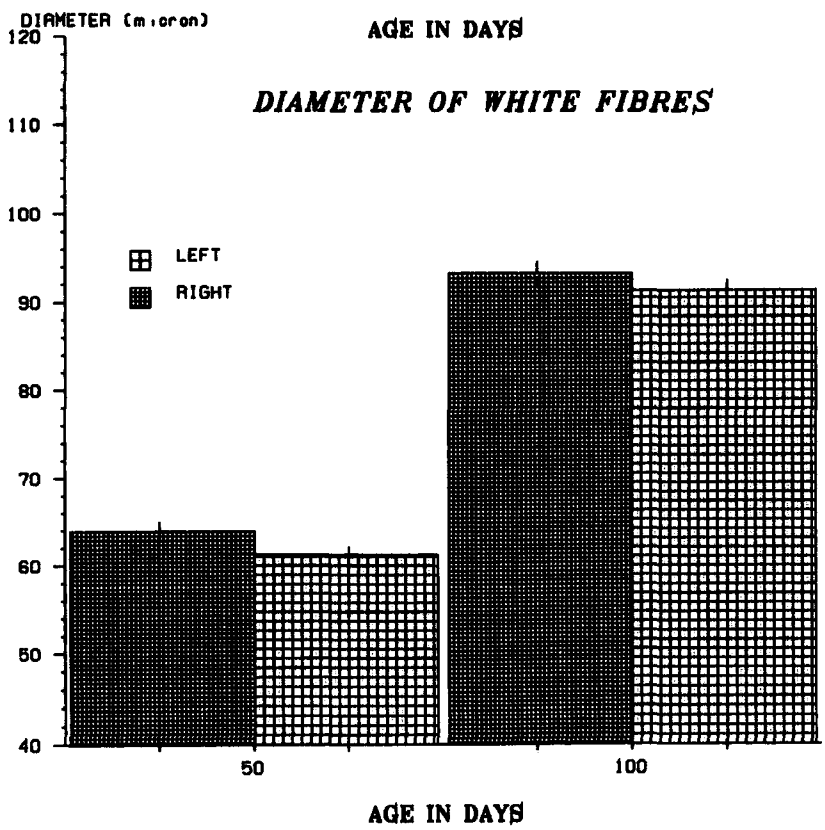
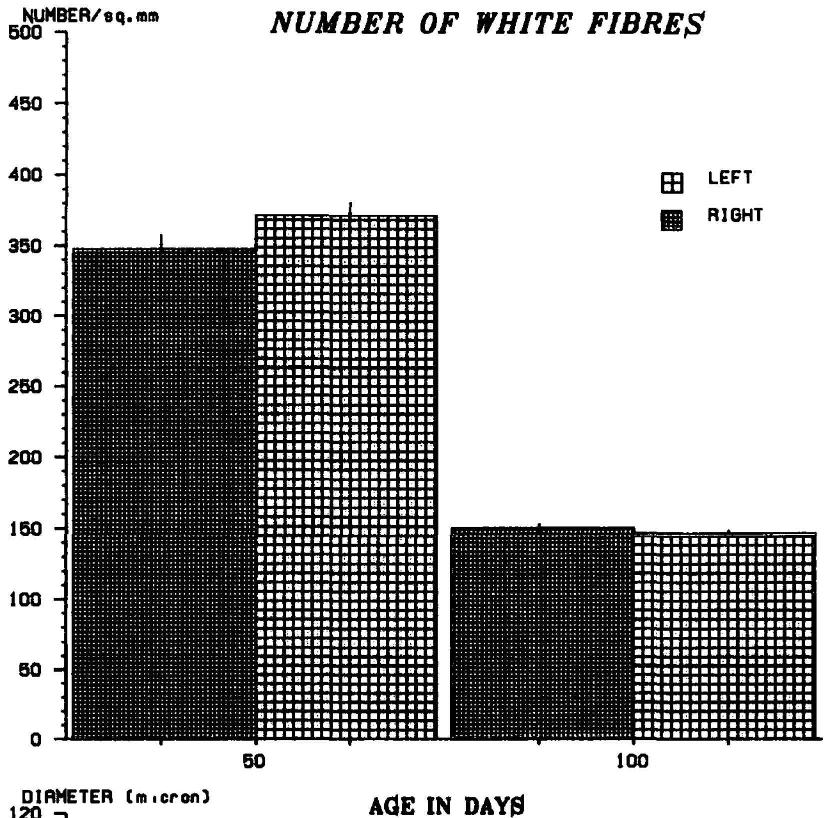


FIGURE 5.5 – WHITE FIBRES(FG) IN THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION B)



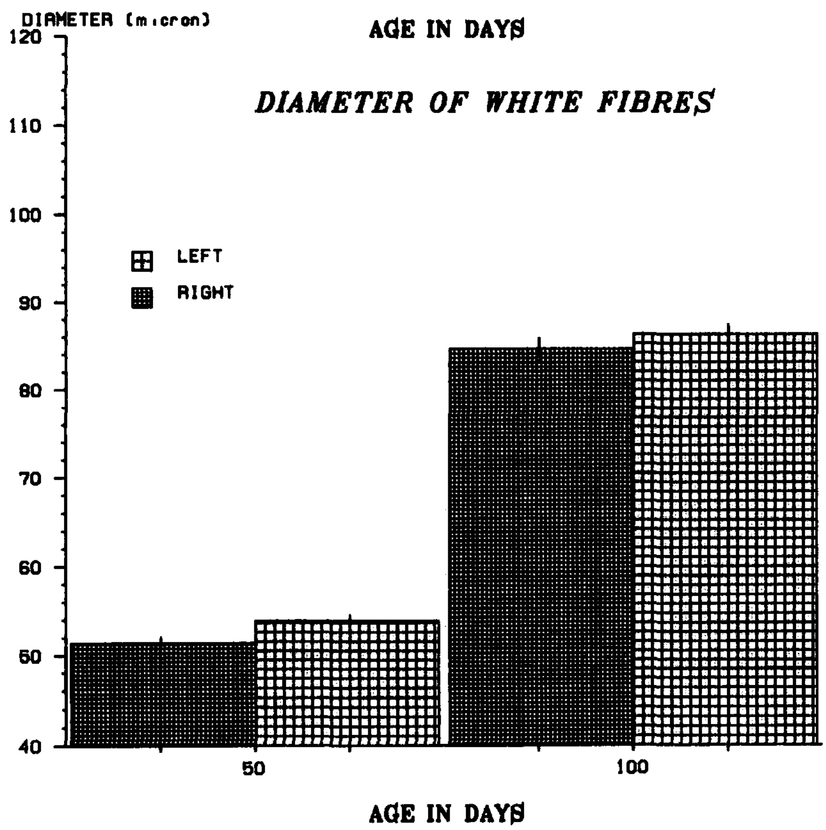
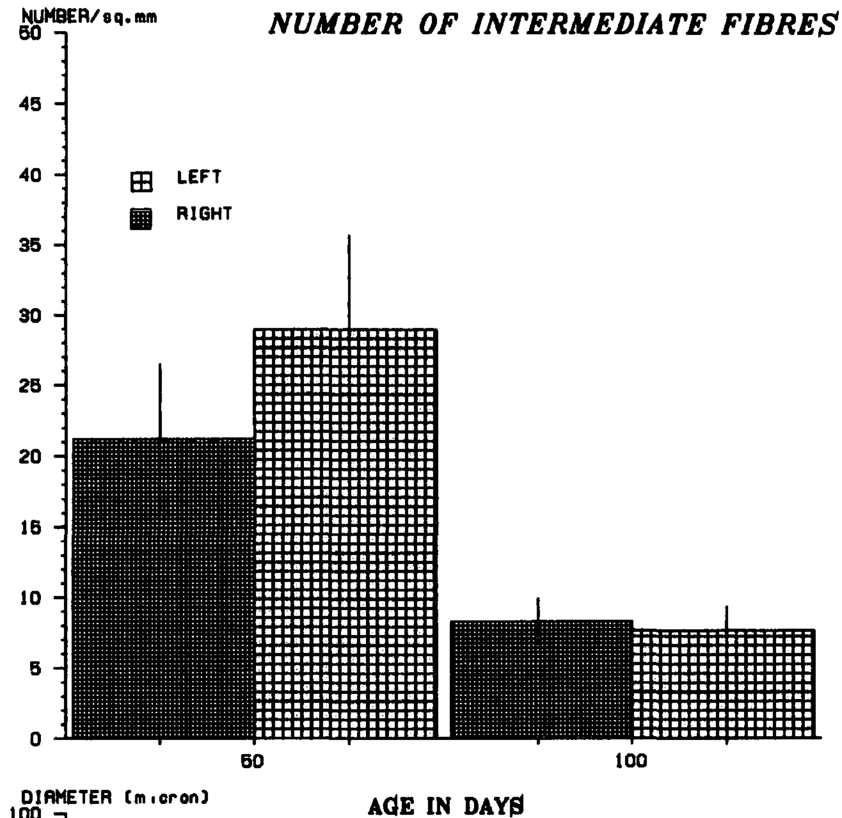


FIGURE 5.6 – INTERMEDIATE FIBRES(FOG) IN THE MOST THREE ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION A)



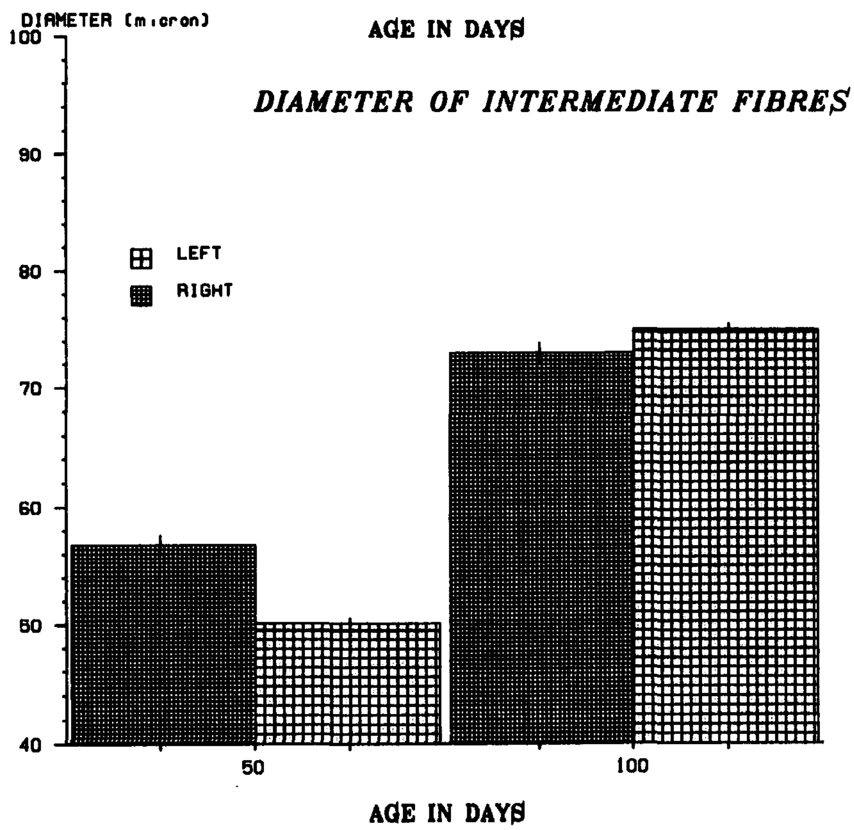


FIGURE 5.7 – INTERMEDIATE FIBRES(FOG) IN THE MOST THREE ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION B)

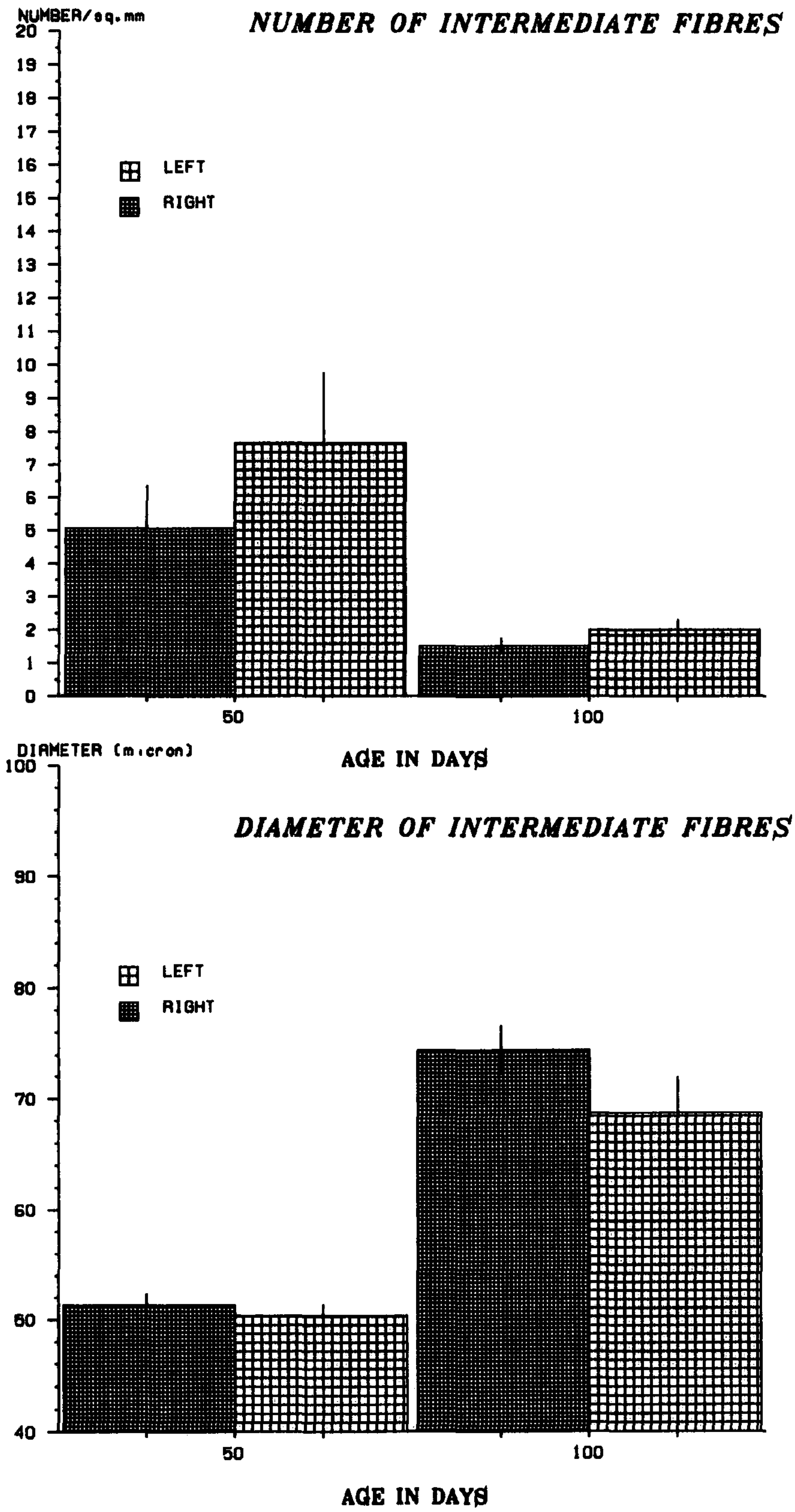


FIGURE 5.8 – RED FIBRES (SO) IN THE MOST THREE ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION A)

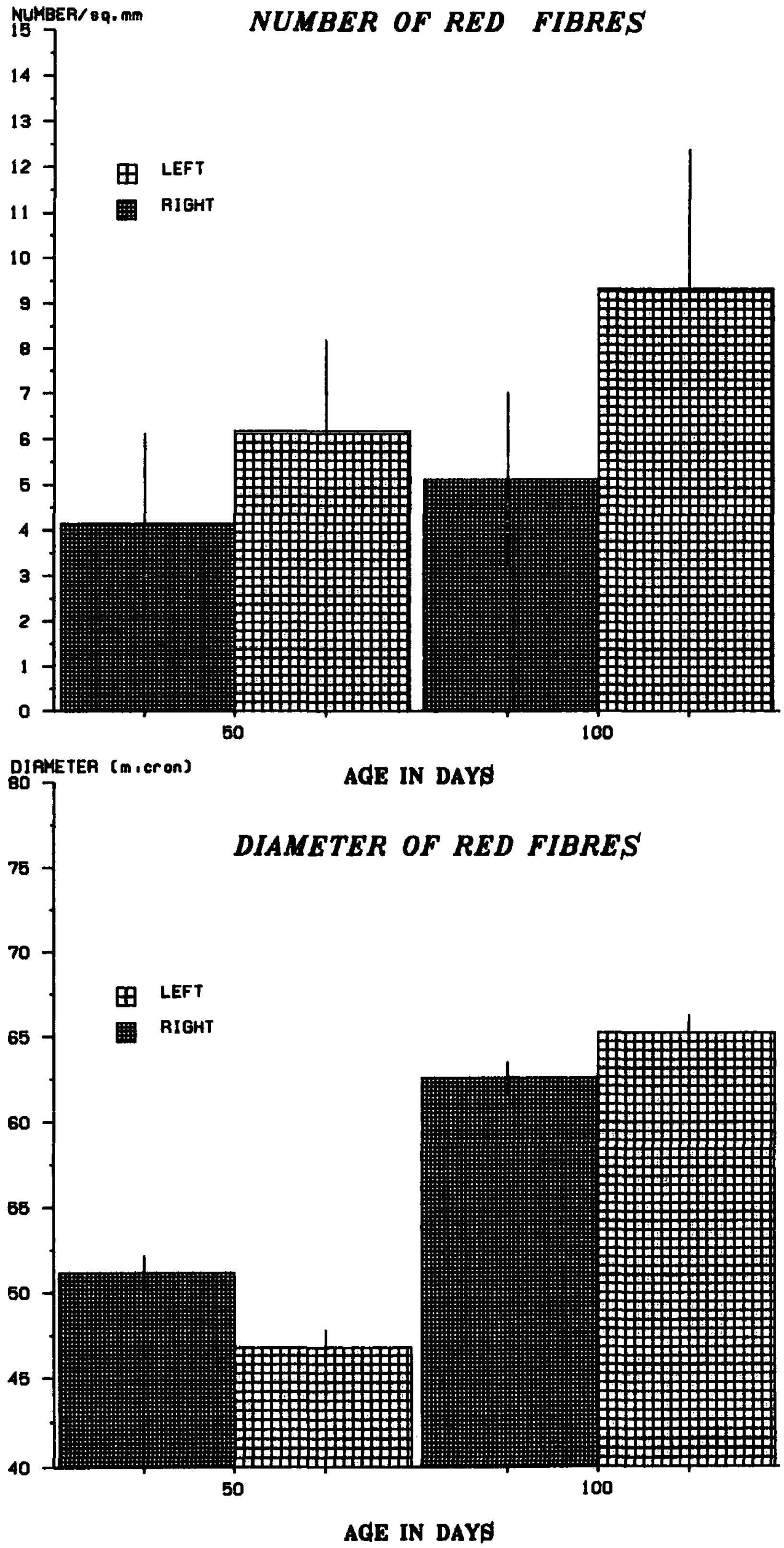
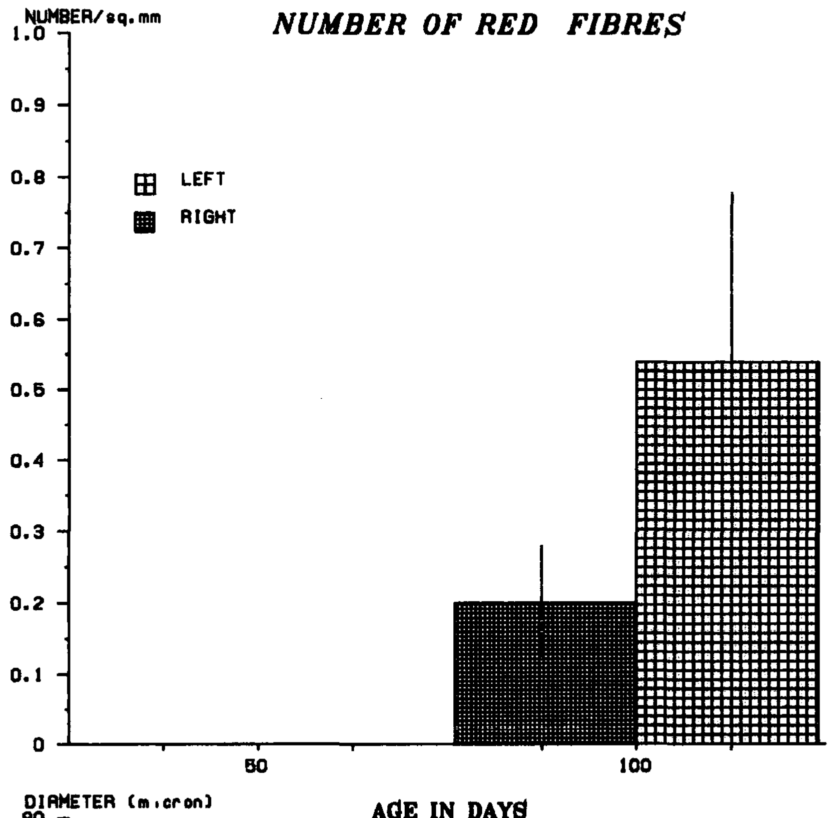
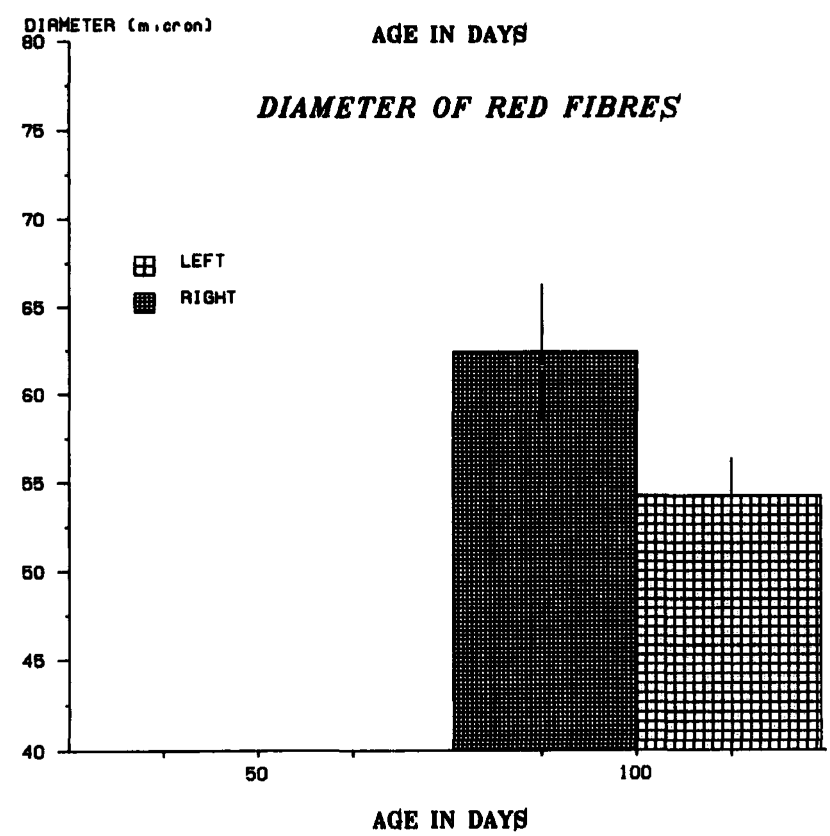


FIGURE 5.9 – RED FIBRES (SO) IN THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES (REGION B)





1. White Fibres (FG)

There were no significant differences between the average fibre diameters in the two sides of the pectoralis muscle in either region at age 50 days, whereas at age 100 days, the right region B had significantly larger white-fibre diameter ($t = 2.298$, $p < 0.05$) than the left, as shown in figure 5.5.

2. Intermediate Fibres (FOG)

There were no significant differences between the diameters of intermediate fibres in the right and left muscles in either regions A or B at age 100 days (see figure 5.6 and 5.7 respectively). However, the right region A had significantly larger intermediate fibre diameters ($t = 6.766$, $p < 0.001$) at age 50 days.

3. Red Fibres (SO)

There were no significant differences in the diameter of red fibres between right and left muscles in region B; however, the right side of pectoralis muscle had a significantly ($t = 2.968$, $p < 0.01$) larger red fibre diameter than the left one in region A as shown in figure 5.8.

It was concluded that the total-fibre and fibre-type numbers between the two sides of pectoralis muscle was not significantly different in either region at age 50 days. Although the degree of asymmetry of the pectoralis muscle of the three selected birds at 50 day of age was high (91.46%), the histochemical result revealed that the diameter of the red and intermediate-fibres were significantly ($t = 2.968$, $p < 0.01$ and $t = 6.766$, $p < 0.001$) greater in the right region A, and the diameter of white fibres was also significantly ($t = 2.298$, $p < 0.05$) greater in the right region B at that age. Moreover, at age 100 days degree of asymmetry in the three selected birds (92.29%) was still high, but the total number of fibres and white-fibres number in the right region A were significantly ($t = 2.450$, $p < 0.05$ and $t = 3.769$, $p < 0.01$ respectively) larger than the left region A, whereas the diameter of fibre types was not significantly different. Thus the right pectoralis muscle in the most asymmetrical chickens was smaller in wet weight but had larger fibre diameters at age 50 days and larger total and white fibre number per square millimeter at age 100 days.

5.5 Skeletal Measurements

The depth, width, and height of the keel were measured, as shown in figure 2.8, plate 2.3, in addition to the breast angle, as shown in figure 2.11, plate 2.5 (see also chapters II, III and VII), in the right and left sides of the skeletons of the three most asymmetrical birds at age 50 and 100 days. The mean with standard error of each of these measurements are presented in table 5.5.

5.5.1 Depth of the Keel

The mean depth of the keel of the right and left sides of the three most asymmetrical birds are plotted in figure 5.10A. Student's *t*-test revealed that the depth of the right side of the keel was significantly greater than that of the left at both ages.

5.5.2 Width of the Keel

There were no significant differences between the keel width of the two sides, as shown in figure 5.10B.

5.5.3 Height of the Keel

Student's *t*-test revealed that the height of the left side was significantly

Table 5.5 — Average Depth, Width and Height of the Keel and Breast Angle in Right and Left Pectoralis Muscle in the Most Asymmetrical Selected Chickens

Mean ± SE given for each measurement

Age in Days		50	100
Number of Birds		3	3
Keel Depth (mm)	R	23.22 ± 0.471	34.85 ± 0.592
	L	20.72 ± 0.358	31.33 ± 0.806
	t-test	$t = 4.226^{*}$	$t = 3.519^{*}$
Keel Width (mm)	R	27.23 ± 1.211	32.10 ± 0.687
	L	27.55 ± 0.929	33.58 ± 1.141
	t-test	N.S.	N.S.
Keel Height (mm)	R	67.40 ± 1.151	95.793± 1.615
	L	72.54 ± 1.034	114.80 ± 3.370
	t-test	$t = 3.320^{*}$	$t = 5.086^{**}$
Breast Angle (Degree)	R	143.33 ± 0.356	153.33 ± 0.844
	L	130.41 ± 0.732	138.85 ± 0.528
	t-test	$t = 15.873^{***}$	$t = 14.549^{***}$

Number of asterisks indicates the degree of significance of the *t*-test between the right and left sides.

greater than the height of the right side at both ages, as shown in figure 5.10C. This result might be a consequence of the significant differences of the depth of the keel.

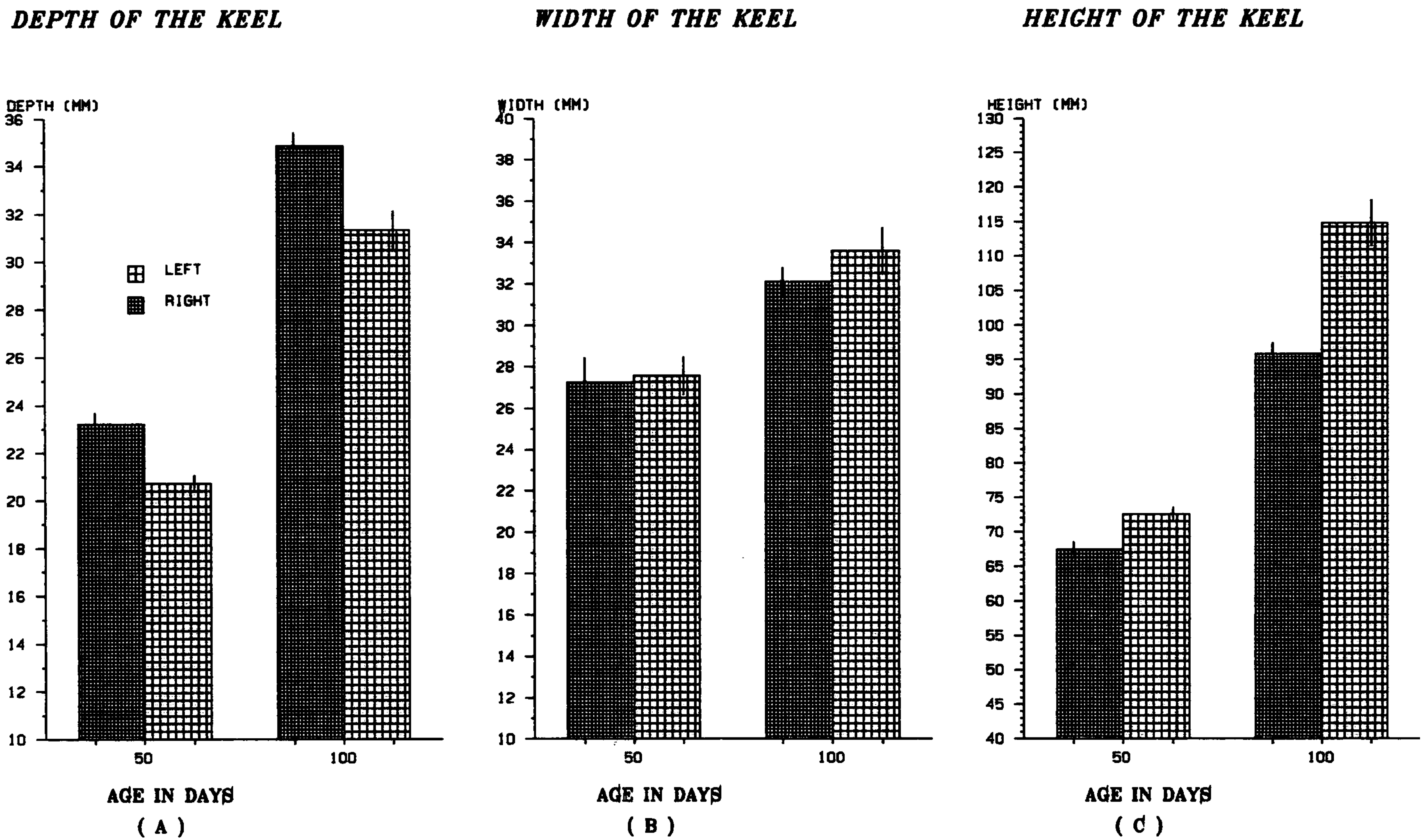


FIGURE 5.10 – DEPTH, WIDTH AND HEIGHT OF THE KEEL IN THE THREE MOST ASYMMETRICAL SELECTED CHICKENS AT TWO AGES

(OVERALL MEAN WITH STANDARD ERROR)

5.5.4 Breast Angle

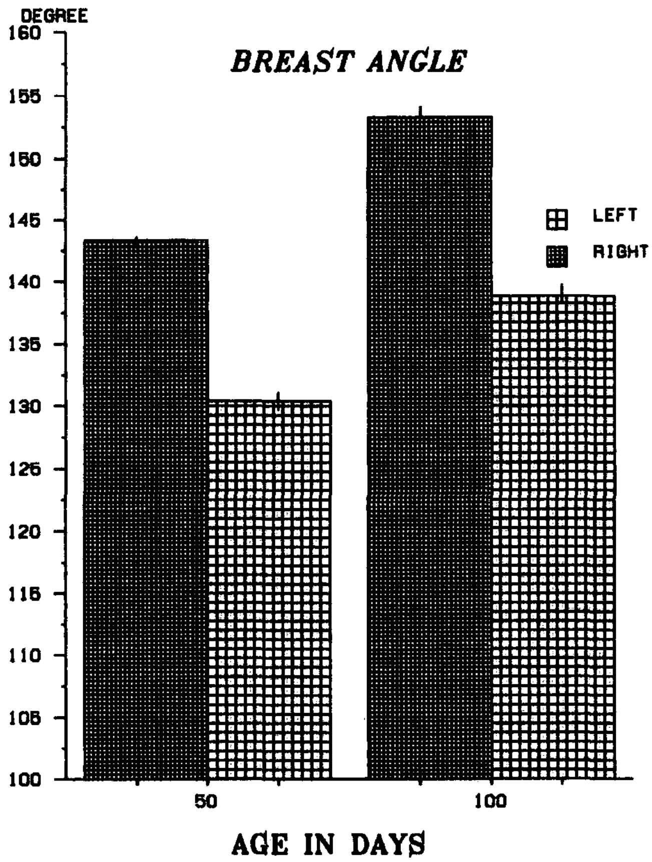
The breast angle is defined as the angle between the sternum and the ventral (sternal) ribs at each side of the breast (see chapters II and VII). The mean the measurements are given in table Student's *t*-test revealed that the right breast angle was very significantly larger than the left one at both ages, as shown clearly in figure 5.11.

It was concluded that the most asymmetrical chickens had asymmetrical keel shapes which might be the main cause of the apparent asymmetry of the pectoralis muscle. This possibility is examined in chapter VII.

5.6 Normal Distribution of Pectoralis Muscle Mass

In order to establish whether 'selected' and therefore supposedly asymmetrical chickens were one extreme of a continuous variation in muscle characteristics, data from all control and selected chickens were pooled and considered as one population to study the frequency distribution of the relative weight of the right and left pectoralis muscles. Data of the relative weight of pectoralis muscle in each individual bird are given in table 5.6. Kolgomorov-Smirnov test result ($D = 0.103$, N.S.) revealed that the distribution of the relative weight of pectoralis muscle of all the birds ($n = 43$ birds) did not differ significantly from normal (see figure 5.12). Also t he skewness and kurtosis values (-0.631 and 0.206 respectively) were not significant from normal. The overall mean of the relative weight of right to left pectoralis muscles was 95.71% and the standard deviation was 3.07%. Although the means of the groups of control and selected chickens were significantly different ($p < 0.05$), as discussed in chapter III, neither the mean of the selected chickens (94.70%) nor the mean of the control chickens (96.66%) differed significantly from

FIGURE 5.11 – BREAST ANGLE IN THE THE THREE MOST SELECTED ASYMETRICAL CHIKENS AT TWO AGES



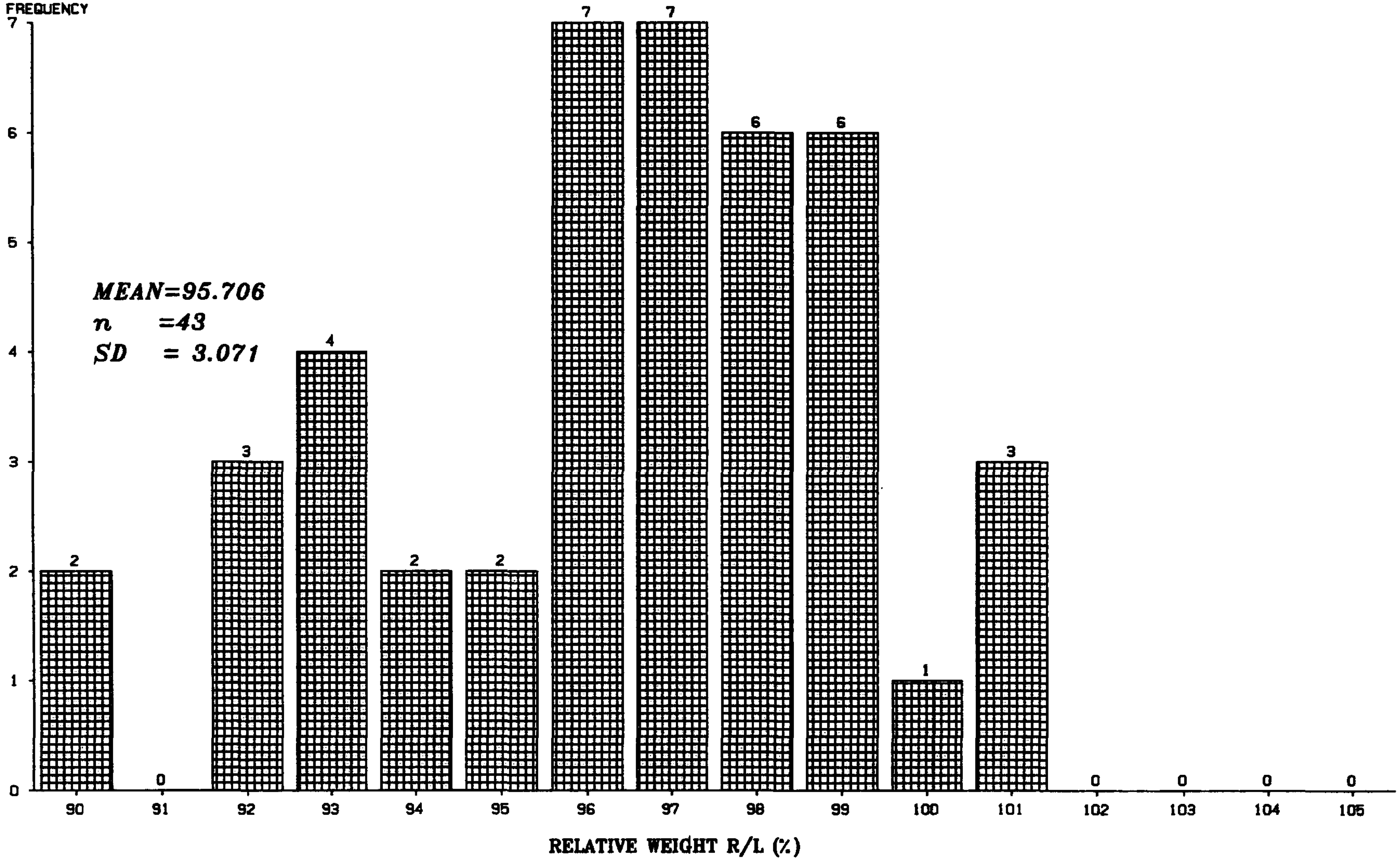


FIGURE 5.12 – THE FREQUENCY OF THE RELATIVE WEIGHT (DEGREE OF ASYMMETRY) OF PECTORALIS MUSCLE (R/L%) IN CONTROL AND SELECTED CHICKENS

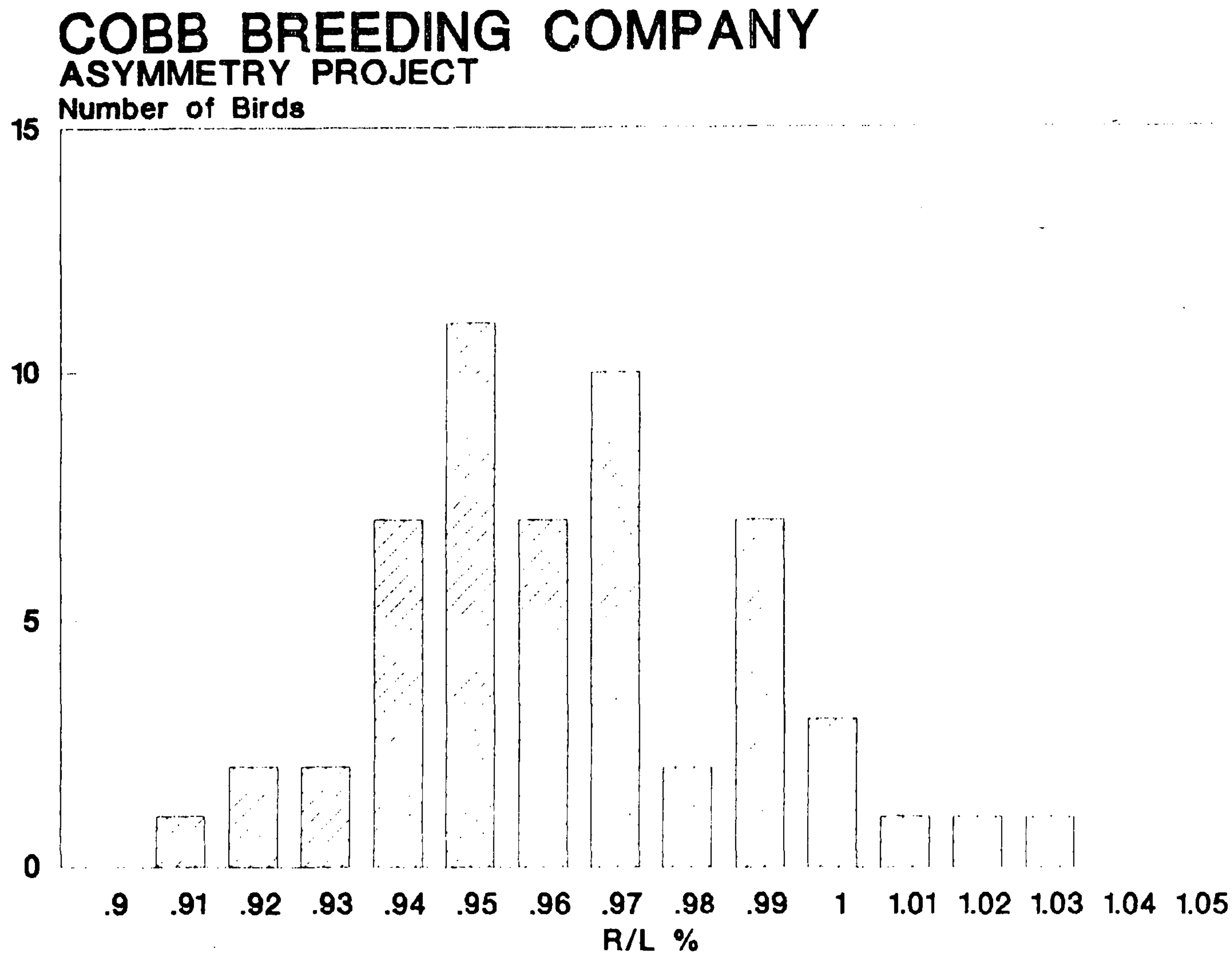


FIGURE 5.13 – THE FREQUENCY OF THE RELATIVE WEIGHT (DEGREE OF ASYMMETRY) OF PECTORALIS MUSCLE R/L %
AT COBB BREEDING COMPANY

Table 5.6 — Relative Weight of Pectoralis Muscle R:L in Each Individual Bird Used for Control and Selected Chickens with Age

Age (Days)	Selected Birds			Mean ± SD	Control Birds			Mean ± SD
	1st	2nd	3rd		1st	2nd	3rd	
20	97.758	92.077	94.657	94.831 ± 2.845	98.738	100.985	100.051	97.377 ± 3.396
30	-	96.591	92.036	94.314 ± 3.221	95.151	98.554	100.824	96.377 ± 3.396
40	97.431	95.828	88.018	93.760 ± 5.063	97.934	91.017	97.213	94.573 ± 4.090
50	91.929	95.411	95.521	94.287 ± 2.043	95.229	98.339	96.617	95.508 ± 2.104
60	97.458	93.484	97.230	96.057 ± 2.231	99.384	96.384	91.075	95.932 ± 3.165
70	98.021	95.300	98.533	97.285 ± 1.738	96.326	93.148	96.151	96.247 ± 1.944
100	88.146	96.343	92.559	92.249 ± 4.102	-	98.433	96.618	94.420 ± 4.107
150	-	94.430	-	94.430	95.411	92.449	-	94.097 ± 3.396
		Overall	Mean	94.703 ± 3.177		Overall	Mean	96.664 ± 2.876

the overall mean. Thus the selected chickens were merely a biased sub-sample within the normal distribution range of the whole population as shown in figure 5.15. In addition to this comparison the two means of the relative weight of pectoralis muscle in these two groups of birds were not significantly different from the relative weight of pectoralis muscle of the Cobb breeding chicken population (1989), as presented in figure 5.13. This confirms that the birds I examined were representative of the whole breeding population, although some individual birds among the 'selected' group had relative muscle weights at the extreme left side of the normal distribution as shown in figure 5.12.

CHAPTER VI

Contents

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Chapter VI

ULTRASONIC TECHNIQUES APPLIED TO MEASUREMENTS ON LIVE CHICKENS

6.1 Introduction

Chapters III and IV have described the results obtained on the pectoralis muscles and some aspects of the skeleton of birds thought to show asymmetry in the muscle at age 20 days by a skilled handler at the Cobb Breeding Company. Results of analysis of variance and regression statistics indicated that there were neither significant differences in the weight or structure of the left and right pectoralis muscle, nor significant differences in the weight or length of the measured skeletal bones. However, some differences in structure were revealed between the selected birds and the controls. Because not all the selected chickens were asymmetrical in pectoralis muscle size, although expected to be so by Cobb, it was necessary to look for a more accurate method to predict and select the birds which would develop asymmetrical shape in the breast, and study them anatomically and histochemically as in the previous groups of chickens.

6.2 Development of Indirect Measurement Techniques

The main tasks of selective breeding for meat production are:

1. to maximize the lean meat combined with tenderness and other factors giving maximum palatablity; and
2. to reduce the excess fat.

These tasks could be achieved by intensive selection of the genotype of the parent stock of meat producing animals for carcass traits which have medium to high heretibility (Warwick and Legates, 1979). However, progress in selecting for carcass traits will be slow if all selection must be based upon information from sib and progeny tests. This accounts for the continuing interest in developing improved methods and techniques to enable animal breeders to evaluate the potential carcass quality in living animals, without sacrificing them so that the animal can still be used for breeding purposes. Also the tremendous variation in both the quantitative and qualitative characteristics of meat animal carcasses emphasizes the need to establish research techniques which will identify the important economic traits in meat and provide a means for standardizing the quality of product made available to consumers. The recent emphasis upon meat research has led to the development of many valuable research techniques.

A *Ruler Probe* technique was developed by Hazel and Kline (1952) for measuring backfat thickness on live hogs. With this method, a small incision is made with a scalpel in the skin and an instrument consisting of a narrow metal ruler is pushed through the fat layers to the underlying muscle epimysium. The reading could be marked after pressure had been released for an instant and the instrument withdrawn. Many readings was obtained and the average could be taken as the thickness of the fat. Good agreement (r = 0.69 to 0.81) was obtained between the live probe technique and backfat thickness measurements in dead carcasses by Hazel and Kline (1953), Hetzer, *et al.* (1956), DePape and Whatley (1956) and Pearson, *et al.* (1957). Therefore this technique has been widely used in swine improvement programmes (Warwick and Legares, 1979) and recent results have been reported to be highly correlated (0.90 or higher) with the percentage of lean in the carcass (Acker, 1983). However the technique is not as accurate an indicator of percentage of lean meat in beef as in pork. The irregular shape of the *Longissimus Dorsi* muscle, or loin eye muscle, makes it difficult to obtain consistent measurements. Therefore it was necessary to develop this or another technique for greater accuracy and applicability to different meat animals and without inflicting tissue damage. Many different techniques were reviewed by Stouffer (1969) and their application to meat research discussed by Bray *et al.,* (1969) and Swatland (1984).

6.2.1 Ultrasonic Technique

Ultrasonic devices have the advantage of inflicting no tissue damage and requiring relatively inexpensive equipment, therefore ultrasonic estimates are being used increasingly in test programmes in animal breeding (Warwick and Legates, 1979).

Ultrasonic devices contain a transducer which emits high-frequency sound waves between 0.5 and 2.5 megacycles into specific tissue layers in intact bodies and carcasses. These high frequency sound waves will penetrate into the underlying tissue of the animal. When the sound waves strike a boundary between two adjacent tissue layers some of the energy will be reflected back to the transducer. Other sound waves will continue on until reflected at subsequent layers and be reflected back to the transducer and displayed on a cathode ray tube (or printed) in proportion to the time that it take them to return. The echoes returning from the various layers of tissue in the object under investigation can be seen simultaneously on a cathode ray tube. The display can be calibrated, by prior knowledge of the velocity of sound in the tissues, to read thickness of fat and muscle layers directly from the cathode tube.

The ultrasonic technique was first used in the medical field in the early 1950's. Later, Temple *et al.*, (1956) reported using ultrasonic equipment for measurement of fat thickness on live cattle. Further applications for measuring backfat thickness in live hogs were reported by Dumont (1959) in France, East *et al.*, (1959) in England, Hazel and Kline (1959), Zobrisky *et al.*, (1961) and Gaarder (1959) in the U.S.A. The correlation coefficient between carcass fat measurements and live animal ultrasonic fat measurements made by these various workers ranged from 0.80 to 0.97. Other workers recognized that the technique could be used to identify lean as well as fat, by measuring the thickness and areas of muscles or the depth of lean and depth of fat as an indication of live animal composition (Price *et al.*, 1960a,b, and Lauprecht, *rt al.*, 1960). Live animal ultrasonic measurements were significantly correlated with carcass composition and their use in the selection of breeding stock was recommended for evaluating muscle and fat in meat animals (Stouffer, 1969).

6.2.1.1 Selection of Chickens by the Ultrasonic Technique

As a result of my unsuccessful search for significant differences in the pectoralis muscle structure or the measured skeletal bones in the chickens selected by a skilled handler at the Cobb Breeding Company, it was decided to use an ultrasonic method to select asymmetrical chickens by using SCANO ULTrASONIC SCANOPROB II, model 731C.

I visited the Cobb Breeding Company after obtaining the results reported in chapters III and IV. The main tasks of my visit were to find out whether the Cobb method of selection of asymmetrical birds by their skilled handler was accurate or not, and to apply the ultrasonic method to a large number of selected birds thought to show asymmetrical growth in the breast muscles. Thickness of the breast muscle (keel depth) in these selected birds was measured in live birds by the researcher at both sides of the anterior part of the keel. Afterwards, birds were killed and the pectoralis and supracoracoideus muscles were immediately weighed. The results were very surprising, that the ultrasonic reading of the breast thickness in live birds was greater on the right side of the breast, whereas the left pectoralis muscle was heavier than the right one, at age 50 and 100 days as shown in tables 6.1 and 6.2). This apparently contradictory result required more investigations on chickens selected by the ultrasonic technique (see Chapters V and VII).

6.3 Conclusion

The ultrasonic technique clearly showed that the asymmetry is not only in the pectoralis muscle but also in the shape of the skeleton especially the keel and the rib-cage. The problem raised by the Cobb Breeding Company was therefore redefined making it necessary to study growth and development of the rib-cage and keel. The results are presented in the following chapter.

Table 6.1 — Live Body Weight, Keel Depth, Muscle Weight, and Degree of Asymmetry in Chickens Selected by Ultrasonic Device at age 50 Days

Bird No.	Body Weight (g)	Ultrasonic Reading (mm) Right	Left	R/L (%)	Muscle Weight Right	Left	Relative Weight R/L (%)
1	1940	21	20	105.00	101.08	105.47	95.84
2†	2160	26	22	118.18	108.08	119.14	90.72
3	2200	20	21	95.24	141.66	145.15	97.60
4†	1990	25	20	125.00	106.35	115.12	92.38
5†	2250	24	21	114.29	115.97	126.75	91.50
6	2060	19	23	82.61	91.97	97.97	93.86
7	2020	23	20	115.00	114.83	117.87	97.42
8	2250	24	20	120.00	112.59	113.52	99.18
9	1940	20	18	111.11	81.96	86.46	94.80
10	2000	21	19	110.53	104.13	112.52	92.54
11	1950	18	17	105.88	71.44	75.17	95.04
12	2150	24	21	114.29	91.94	95.86	95.91
13	2300	24	22	109.09	138.45	134.62	102.85
14	1700	20	19	105.26	86.90	91.67	94.80
15	2130	23	22	104.55	117.00	111.67	104.77
16	2120	23	23	100.00	111.52	118.77	93.90
Mean	2072.50	22.19	20.50*	108.50	105.99	110.48	95.82
± SE	38.411	0.586	0.428	2.568	4.682	4.499	0.966

†These birds were used for anatomical and histochemical studies described in Chapter V.

* Degree of significance of Student's *t*-test between the right and left ultrasinic reading ($p > 0.05$).

Table 6.2 — Live Body Weight, Keel Depth, Muscle Weight, and Degree of Asymmetry in Chickens Selected by Ultrasonic Device at age 100 Days

Bird	Body Weight	Ultrasonic Reading (mm)			Muscle Weight		Relative Weight
No.	(g)	Right	Left	R/L (%)	Right	Left	R/L (%)
1	5470	35	36	97.22	370.83	394.62	93.97
2†	6340	39	34	114.71	382.72	421.40	90.82
3	4650	37	35	105.71	360.45	371.60	97.00
4†	6350	40	34	117.65	448.29	482.18	92.97
5†	5800	39	33	118.18	341.47	366.90	93.07
6	5150	34	36	94.44	280.09	282.50	99.15
7	5350	38	35	108.57	385.00	399.89	96.28
8	4750	36	33	109.09	252.47	251.30	100.47
9	6550	34	33	103.03	397.35	398.95	99.60
10	6000	35	34	102.94	405.67	404.64	100.25
11	6100	34	35	97.14	384.57	403.48	95.29
512	5650	38	35	108.57	346.66	360.12	96.26
13	6450	38	34	111.76	443.30	464.96	95.34
14	4720	35	33	106.06	280.49	289.49	96.89
Mean	5666.43	36.57	34.29**	106.79	362.81	378.00	96.24
± SE	178.626	0.562	0.286	1.982	15.682	17.595	0.783

†These birds were used for anatomical and histochemical studies described in Chapter V.

** Degree of significance of Student's t-test between the right and left ultrasinic reading ($p > 0.01$).

CHAPTER VII

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Chapter VII

SKELETAL ASYMMETRY

7.1 Introduction

The end point of the breeding enterprise for meat production is saleable animal carcass. Live weight, carcass weight and an index of muscularity and fat content are almost universal measures of this end product in both commercial agriculture and agricultural research. This led breeders to select their breeding stocks using live weight and some other characters as selection indices for breeding and development of poultry (see chapter I). Since muscle, biologically, can not be produced without a minimum of bone support, the ratio of muscle to bone weight offers an index for selection purposes of the degree of carcass muscling. This fact was neglected by or unknown to breeders in the last few decades. As a result an increasing problem of the broiler industry has been the loss of a large number of chickens through necessary culling and downgrading of birds suffering from skeletal abnormality of their legs and vertebral columns (Wise, 1970b). Fraser (1965) reviewed the common causes of lameness in domestic poultry. Subsequently, Wise (1975) reviewed the more important skeletal abnormalities of poultry and Riddle (1975) discussed in detail those skeletal abnormalities of the fowl and turkey which have genetic or unknown aetiology. Many workers in poultry development consider such skeletal problems as the inevitable consequence of the selection of birds on only live weight gain, and of feeding them rations of high calorific density in environments providing little need or opportunity for exercise (Wise, 1970b; Riddle, 1975; Wilson, 1980).

Carcass shape is probably involved in consumer preferences and in many national grading systems. Since the breasts of some individual birds of the Cobb 500 strain of broiler chickens exhibit apparent differences in shape or size between the right and left sides, some measurements on the keel bone, rib-cage and the pectoralis muscle lying laterally to it were made. From these, attempts were made to examine the anatomical structure underlying the convexity of the breast of chickens.

7.2 The Skeleton of Poultry

The skeleton of poultry is derived from that of primitive birds. The avian skeleton is adapted for flight. Moreng and Avens (1985) summarize the differences between avian and mammalian skeleton as follows: in birds these are:

1. fewer bones,
2. many fused bones,
3. higher mineral content of bones,
4. pneumatic bones filled with air instead of marrow,
5. the epiphyseal plate has blood vessels that penetrate deeply into zones of cellular proliferation, whereas in mammals, the epiphyseal plate is almost devoid of such vessels.

Abnormalities in poultry skeletons have appeared increasingly in the recent breeds of poultry (Wise, 1970a; Wise, 1970b). This problem has probably arisen because the assumption has been made that selection for growth rate would result in proportional increases in all body parts; however, intensive selection for body weight and breast conformation has resulted in greater increases in breast than in leg and skeletal masses (Havenstein, *et al.,* 1988). As a consequence of this selection disproportionate changes in body parts appear to have contributed to leg and skeletal problems in fast-growing poultry meat lines (Nestor *et al.,* 1988 and Havenstein, *et al.,* 1988).

7.2.1 The Rib-Cage of the Chickens

The rib-cage, consisting of the sternum, costal cartilages and the seven pairs of ribs, has the mechanical role of protecting and supporting internal organs (heart, lungs, liver, etc.) and of allowing motion of the trunk in respiration as well as in spinal flexion. The two anterior pairs of ribs are free while the last five are attached to the sternum. Ribs 2 to 6 each has an *uncinate process* which overlaps with the next posterior rib. Each rib (except in the case of the first two) consists of two parts: a dorsal or *vertebral rib* and a ventral or *sternal rib* (see figure 2.5, plate 2.2). The articulation of the rib-cage with the sternum and its movement are explained in detail by Ede, (1968), Swatland (1984) and Morenge and Avens (1985).

The sternum is extremely large and it is formed by a number of closely joined bones, the *sternebrae.* It has a conspicuous ventral ridge in the midline, the keel or *carina* , which increases the area that is available for the attachment of the flight muscles. The dorsal surface of the expanded sternum is concave, and it forms the floor of a continuous thoracic and abdominal cavity.

7.2.2 Description of Rib Shape

The external shape of the chickens breast is caused by meat depth bulges on the keel and the convexity of the breast. This carcass shape is very much

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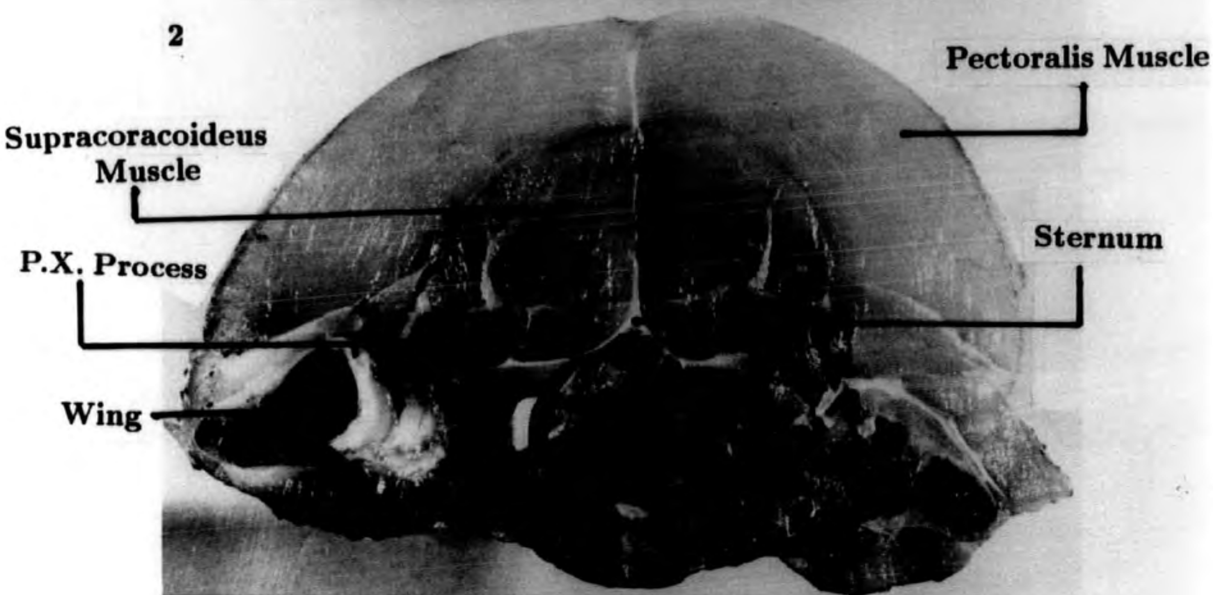

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PLATE 7·1

LEFT SIDE OF
THE BIRD

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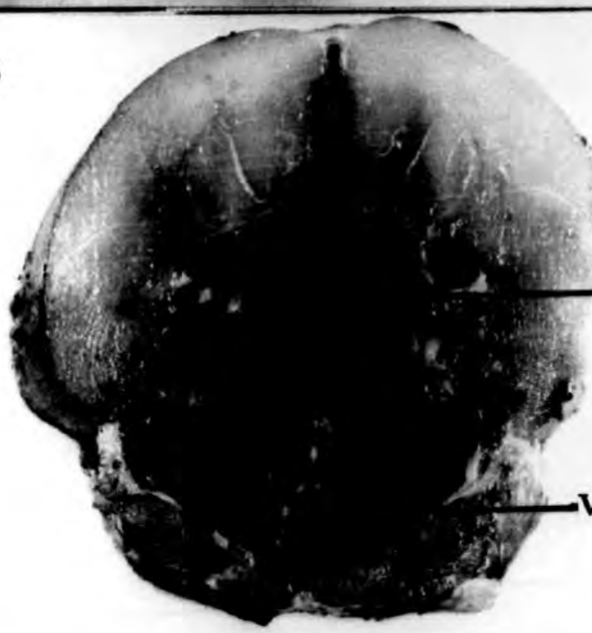

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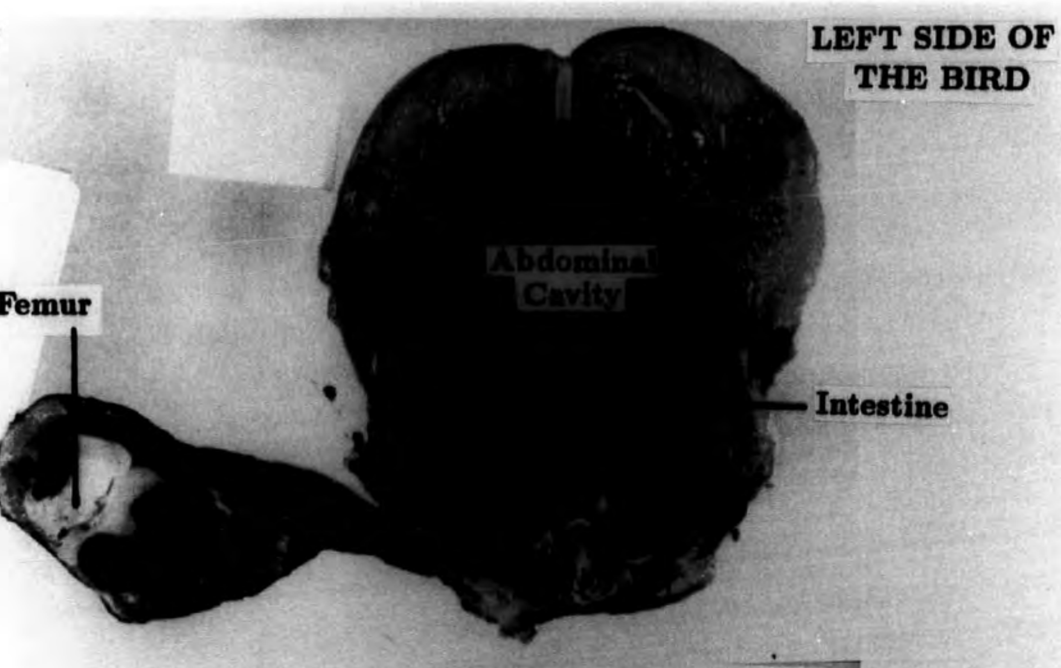
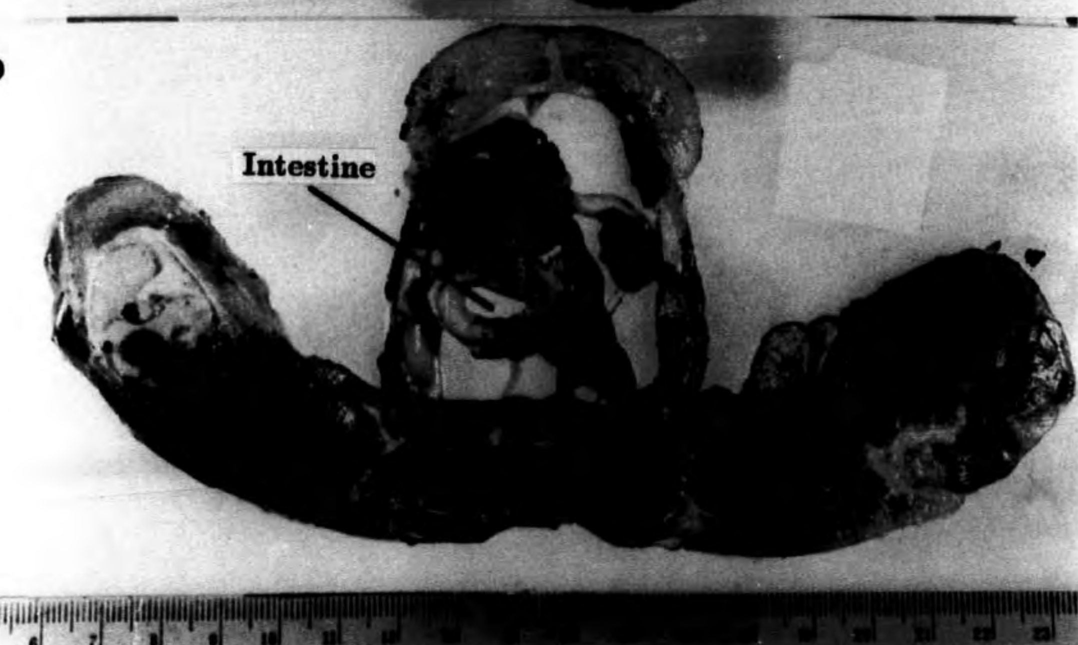

LEFT SIDE OF
THE BIRD
Abdominal
Cavity
Femur
Intestine

8

9


Intestine

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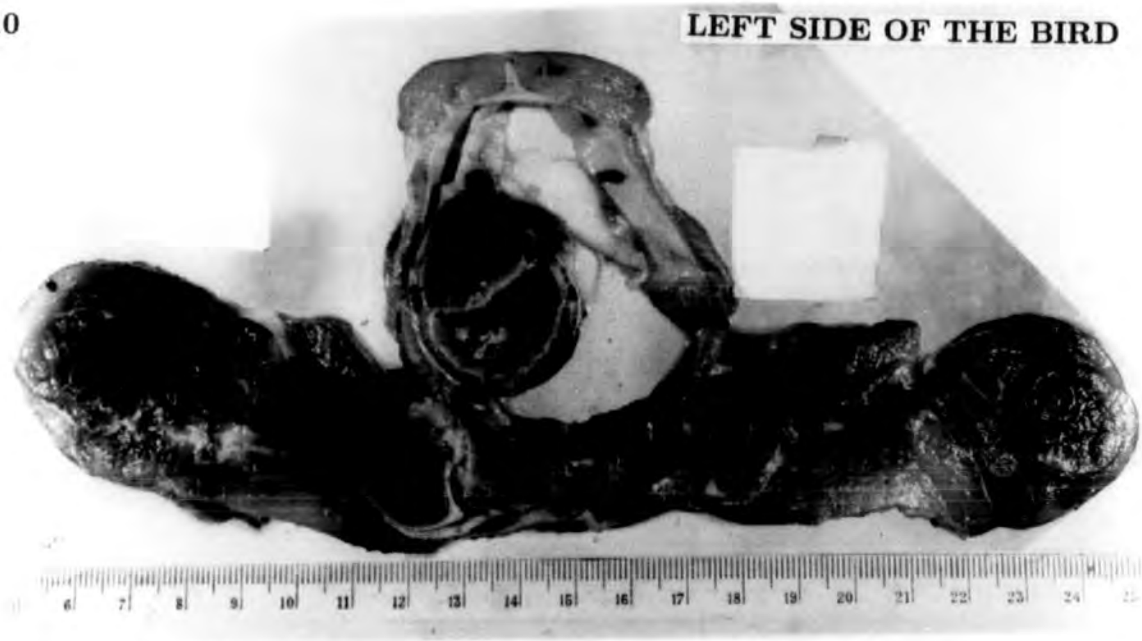


Figure 7.1 – Cross-section of the whole selected frozen bird age 100 days showing marked asymmetry in the shape of the breast muscles and rib-cage.

PLATE 7·1

appreciated by the consumer and is important for carcass grading. Therefore, recently, some workers have considered the shape of the carcass in the selection index of their improvement and development programmes (Swatland, 1979).

Ideally, transverse sections of the rib-cage should show a midline axis of symmetry. I examined this in a whole frozen bird which showed an asymmetrical external appearance in breast shape. The bird was sectioned by band saw into ten sections. Photographs taken of these sections are shown in figure 7.1 (plate 7.1). These provide clear evidence that asymmetry in the shape of the breast was due to asymmetry of the keel and rib-cage. The ribs of the left side of the cage were less rounded than those on the right side of the cage, as shown in figure 7.9 (plate 7.3).

Accordingly, I made measurements on the geometry of the rib-cage, following the methods of Wilson, *et al.,* (1987) and Dansereau and Stokes (1988). These measurements are as follows:

1. Intrinsic (shape) Measurements (see figure 2.9, plate 2.3)

   a) Arc Length: calculated as the total distance of straight segments between measured points on the rib. Distances between points were normally 5 mm up to a maximum of 10 mm, depending on the curvature of the rib.

   b) Chord Length: the straight line distance between the *costovertebral* junction and *costochondral* junctions.

   c) Enclosed Area: the area bounded by the rib and the chord.

All of these measurements were calculated with respect to a best-fit plane of the bony (vertebral) part of each rib at each side since it was found that the rib midline lay close to a flat plane.

2. Extrinsic (orientation) Measurement (see figure 2.9, plate 2.3)

   a) Rotation Angle: The measurement of rib orientation is the angle made by the best-fit plane of the vertebral rib to the horizontal line of the thoracic column.

The intrinsic and extrinsic measurements data from individual birds at 50 and 100 days of age are presented in appendix D. Mean values of these measurements are presented in this chapter. Other measurements on the sternum and the pectoralis muscles were taken and presented in a similar way. In addition to the anatomical measurements on dead birds, keel depth on live birds was obtained using an ultrasonic method (see chapter VI).

Asymmetry measurements were obtained by comparing side-to-side differences. Asymmetry was defined as the value of the right side divided by the value of the left side and expressed as a percentage (as shown in all tables in appendix D). One-way ANOVA was used to test whether the values of the two sides were different for each measurement.

7.3 Ultrasonic Measurements in Live Birds

The mean keel depth in live birds and the mean body weight with the standard deviation are presented in table 7.1, and plotted in figure 7.2 (measurements on individual birds for age 50 and 100 days are given in tables D1 and D2 of appendix D).

Average live weight increased 2.38 times between 50 and 100 days of age, whereas the keel depth on the right and left side increased 1.58 and 1.68 times

Table 7.1 — Average Body Weight and Keel Depth of Live Chickens Selected as Showing Pectoral Asymmetry and Comparison of Right and Left Sides by One-Way ANOVA

Age (days)	No. of Birds (n)	Live Weight (g) $\pm SD$	Keel Depth (mm) Right $\pm SD$	Left $\pm SD$	F-test Ratio	Degree of Significance
50	8	2351.25 ± 148.56	25.00 ± 1.41	21.50 ± 1.31	26.136	***
57	9	3018.89 ± 194.26	26.00 ± 0.71	24.17 ± 0.75	28.471	***
64	9	3712.22 ± 213.24	29.44 ± 2.01	27.11 ± 1.62	26.136	***
70	9	4191.11 ± 206.36	32.56 ± 1.51	29.56 ± 1.13	22.781	***
77	9	4757.22 ± 331.75	34.00 ± 1.50	31.33 ± 1.94	10.667	**
84	7	5260.00 ± 241.18	35.29 ± 1.89	32.86 ± 2.04	5.359	*
91	7	5492.86 ± 251.11	37.00 ± 2.16	34.43 ± 1.81	5.818	*
98	6	5586.00 ± 478.00	39.40 ± 2.88	34.40 ± 2.30	9.193	*

times respectively in the same period.

Analysis of variance revealed that keel depth on the right side was significantly different from that on the left as shown in table 7.1. The significance of this difference was very high at an early age, but gradually decreased with age. This highly significant difference at the early age might be due to the high growth rate observed at early age.

7.4 Measurements on the Pectoralis Muscle

Many measurements were taken on the right and left sides of the pectoralis muscles for each individual bird. Data on the weight, thickness, length, width and length of the fascicle of the pectoralis muscle at ages 50 and 100 days are given in

FIGURE 7.2– LIVE BODY WEIGHT IN CHICKENS SELECTED FOR PECTORAL ASYMMETRY

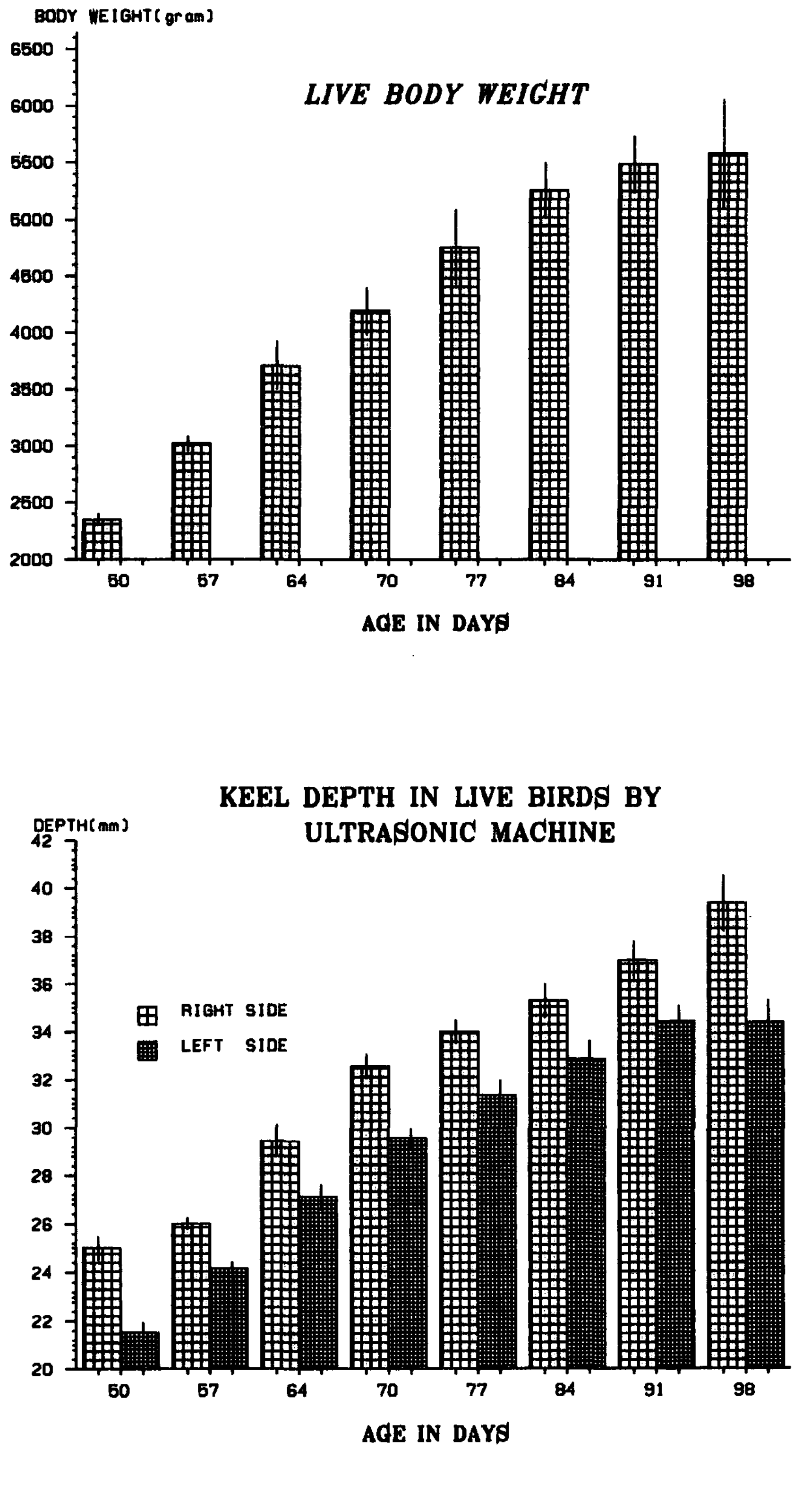


Table 7.2 — The Means and Standard Deviations of Various Measurements on the Pectoralis Muscle at Age 50 and 100 Days

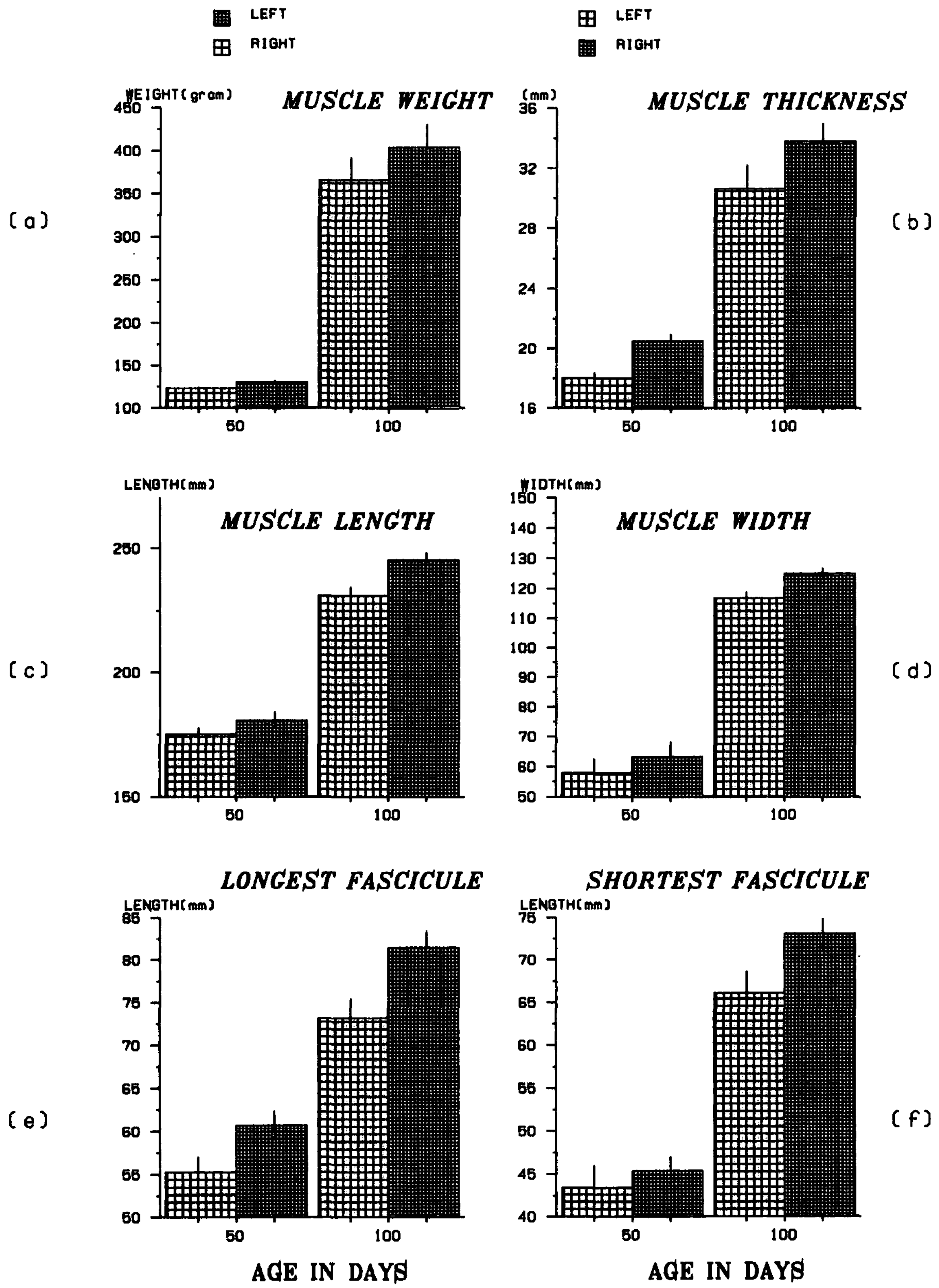
		Age in Days					
		50 Days (n=8)			100 Days (n=6)		
		Mean ± SD	F–Ratio	Degree of Sig.	Mean ± SD	F–Ratio	Degree of Sig.
Live Weight (g)		2351.25 ± 148.56			5521.67 ± 611.70		
Muscle Weight (g)	R	123.05 ± 3.39	9.827	**	366.14 ± 65.14	0.99	N.S.
	L	130.25 ± 5.55			404.10 ± 66.99		
Keel Depth in Live Bird (mm)	R	25.00 ± 1.41	26.385	***	40.33 ± 1.75	7.211	*
	L	21.50 ± 1.31			37.00 ± 2.00		
Pectoralis Muscle Thickness(mm)	R	18.00 ± 1.07	15.909	**	30.67 ± 3.93	2.503	N.S.
	L	20.50 ± 1.41			33.83 ± 2.93		
Pectoralis Muscle Length(mm)	R	175.00 ± 7.15	1.984	N.S.	231.17 ± 8.93	8.904	*
	L	180.50 ± 8.42			245.33 ± 7.45		
Pectoralis Muscle Width(mm)	R	57.91 ± 3.94	9.157	**	116.83 ± 5.35	7.671	*
	L	63.23 ± 3.04			125.00 ± 4.86		
Longest Fascicle (mm)	R	55.28 ± 4.98	4.955	*	73.18 ± 5.58	5.749	*
	L	60.68 ± 4.74			81.43 ± 6.33		
Shortest Fascicle(mm)	R	43.42 ± 5.61	0.550	N.S.	66.05 ± 6.19	5.003	*
	L	45.35 ± 4.77			73.04 ± 4.50		
Breast Angle (Degree)	R	147.38 ± 10.76	16.931	***	148.33 ± 6.71	73.753	***
	L	125.00 ± 10.99			118.17 ± 5.38		

table D.2 and D.2 of appendix D. The mean values of each measurement for each age group are presented in table 7.2.

7.4.1 Weight of the Pectoralis Muscle

The average weight of the right pectoralis muscle was significantly less than the left muscle at age 50 days, but there was no significant difference between the two sides at age 100 days (see figure 7.3a).

FIGURE 7.3– PECTORALIS MUSCLE WEIGHT, THICKNESS, LENGTH, WIDTH AND FASCICLE LENGTH IN CHICKENS SELECTED FOR PECTORAL ASSYMMETRY AT AGE 50 AND 100 DAYS



7.4.2 Thickness of the Pectoralis Muscle

The thickness of the pectoralis muscle in the anterior region A (as described in chapter II) was measured ultrasonically after removing the muscle from the keel. In some muscles the accuracy of the ultrasonic technique was checked using a needle probe. The overall mean with standard deviation is given in table 7.2, and data were plotted in figure 7.3b. Analysis of variance showed that the left side of the pectoralis muscle was significantly thicker than the right side at age 50 days, but not significantly so at age 100 days, although the depth of the keel on the right side was greater on live birds, as discussed in the previous section (7.3). Indeed direct measurement of the right side of the keel itself (after dissecting and removing the flight muscles) showed that it was significantly deeper than the left side.

7.4.3 Length of the Pectoralis Muscle

The length of the pectoralis muscle of each side did not show any significant differences at age 50 days, however at 100 days, the left muscle was significantly longer ($p > 0.05$) than the right muscle as shown in figure 7.3c.

7.4.4 Width of the Pectoralis Muscle

Analysis of variance revealed that the left pectoralis muscle was significantly wider at both ages as shown in figure 7.3d.

7.4.5 Fascicle Length in the Pectoralis Muscle

The longest and shortest fascicles inserting into corresponding areas of the pectoralis muscle at each side of the keel were identified (see figure 2.10, plate 2.4) and their lengths measured. Analysis of variance shows that fasciculi at the left side were significantly longer than at the right side, as shown in table 7.2 and figures 7.3e and 7.3f.

7.5 Breast Angle

Breast angle is the angle between the sternum and the ventral (sternal) ribs at each side of the breast. This angle was measured by Depth Gauge (Model 44M, Moore & Wright) after removing all flight muscles from the sternum and other tissues around the ribs, as shown in figure 2.11, plate 2.5. Measurements are plotted in figure 7.4. Analysis of variance revealed that the right side breast angle was significantly larger than the left side (see figure 7.8, plate 7.2). This was associated with more highly curved ribs as shown on figure 7.9, plate 7.3, and a significantly deeper keel on the right side.

In summary, the left pectoralis muscle of asymmetrical birds was significantly heavier than the right only at 50 days of age, although some other measurements of the carcass were significantly different at 100 days of age (e.g. keel depth, width and length of the pectoralis muscle, length of fasciculus, and the breast angle as shown in table 7.2). Therefore, asymmetry in the skeleton did not cause asymmetry in the pectoralis muscle mass at 100 days of age. However, at 50 days of age when the growth rate is high, asymmetry in pectoralis muscle mass was observed.

7.6 Weight and Length of Individual Bones

Several pairs of bones were chosen for measurements of their length and weight in both the right and left side of each bird. These bones are: coracoid, clavicle, scapula, and posterior and anterior xiphisternal processes, in addition to the keel depth and keel width. The means with standard deviations of these measurements

FIGURE 7.4– BREAST ANGLE IN CHICKENS SELECTED FOR PECTORAL ASYMMETRY AT AGE 50 AND 100 DAYS

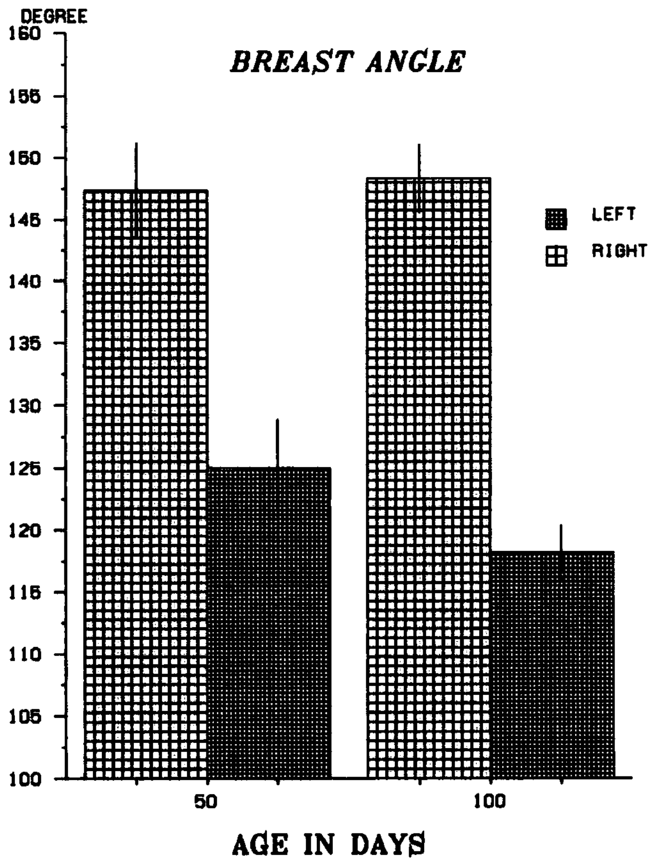


Table 7.3 — Average Weight and Length of Some Bones in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

		Age in Days					
		50 Days (n=8)			100 Days (n=6)		
		Mean ± SD	*F*–Ratio	Degree of Sig.	Mean ± SD	*F*–Ratio	Degree of Sig.
Coracoid Weight	R	1.97 ± 0.11	0.025	N.S.	4.90 ± 0.51	0.230	N.S.
(g)	L	1.96 ± 0.14			4.76 ± 0.45		
Coracoid Length	R	51.39 ± 2.19	0.008	N.S.	70.58 ± 2.07	0.255	N.S.
(mm)	L	51.48 ± 2.03			71.27 ± 2.64		
Scapula Weight	R	1.03 ± 0.12	0.125	N.S.	2.46 ± 0.25	1.021	N.S.
(g)	L	1.04 ± 0.07			2.64 ± 0.35		
Scapula Length	R	65.98 ± 3.41	1.273	N.S.	94.20 ± 2.52	0.086	N.S.
(mm)	L	67.59 ± 2.14			94.60 ± 2.19		
Clavicle Length	R	34.41 ± 2.05	0.276	N.S.	58.29 ± 1.80	0.617	N.S.
(mm)	L	44.09 ± 3.04			59.18 ± 2.08		
P.X. Process	R	52.25 ± 2.42	0.000	N.S.	70.03 ± 4.20	0.489	N.S.
Length (mm)	L	52.27 ± 3.13			71.68 ± 3.99		
A.X. Process	R	30.26 ± 2.21	0.049	N.S.	33.90 ± 4.24	0.120	N.S.
Length (mm)	L	30.50 ± 2.17			33.88 ± 2.88		
Keel Depth	R	23.29 ± 1.14	20.480	***	35.89 ± 2.42	6.045	*
(mm)	L	21.11 ± 0.75			32.72 ± 2.04		
Keel Width	R	30.88 ± 1.76	8.930	**	45.84 ± 1.83	5.265	*
(mm)	L	33.40 ± 1.61			48.25 ± 1.81		

were calculated and are presented in table 7.3, and the data were plotted in figures 7.5 and 7.6. (Measurements for individual birds at 50 and 100 days of age are given in tables D.4 and D.5 respectively in appendix D). Analysis of variance showed that the sizes of bones of each pair did not differ significantly except for keel depth and

FIGURE 7.5– CORACOID, SCAPULA, A.X. PROCESS AND P.X. PROCESS WEIGHT AND LENGTH IN CHICKENS SELECTED FOR PECTORAL ASYMMETRY

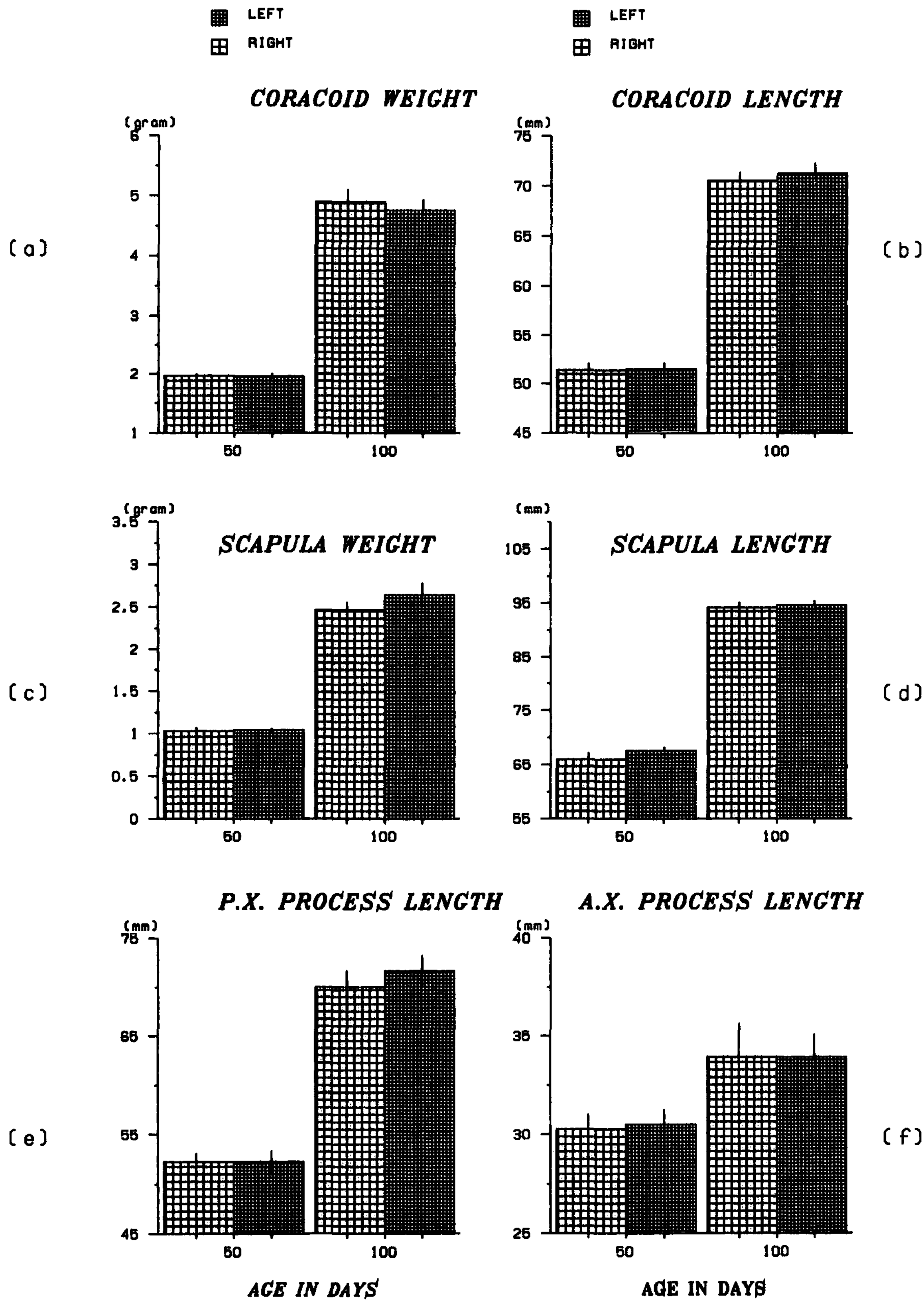
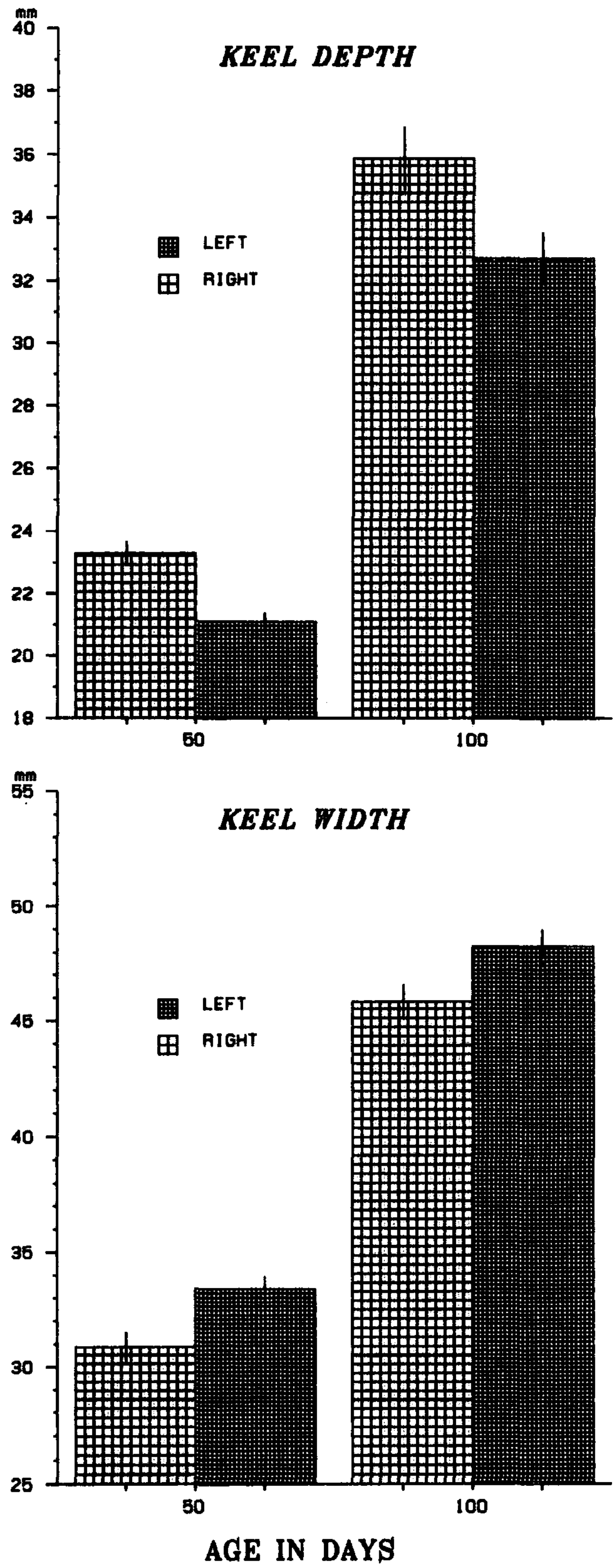


FIGURE 7.6 – KEEL DEPTH AND WIDTH IN CHICKENS SELECTED FOR PECTORAL ASYMMETRICAL AT AGE 50 AND 100 DAYS



keel width. The right side of the keel was significantly deeper than the left one, whereas the left side was significantly wider as shown in figure 7.6 (see plates 7.2 and 7.3).

7.7 The Rib-Cage

The shape of the rib-cage was studied by taking several different measurements on ribs and the rib-cage. These measurements are: weight and length of the ribs; arc and chord length; enclosed area and height; and the orientation of the dorsal angle of the ribs (see figure 2.9, plate 2.3). Data collected from the individual birds are given in appendix D.

7.7.1 Weight and Length of the Ribs

To ensure complete removal of soft tissues, the whole rib-cage of each bird was boiled in a pressure cooker, (see chapter II) then the ribs were carefully exarticulated at the costo-vertebral joints and freed from adherent soft tissues. Each pair of ribs was fixed on graph paper and a photograph taken for further measurements (see figure 7.9, plates 7.3). The length of each rib (for both the sternal and vertebral parts) was measured along its outer surface. Then the weight of the two parts of each rib was taken. Data from birds of age 50 and 100 days are given in tables D.6 and D.7 respectively in appendix D. Since there were no significant differences between each pair of ribs either in length or in weight, the overall mean of these measurements is not presented in this chapter.

7.7.2 Intrinsic Measurements on the Ribs

Arc length, chord length, enclosed area, and height of the ribs were measured for each bird at 50 and 100 days of age. Data are given in tables D.8–D.17 and

Table 7.4 — Average Arc Length of the Ribs in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

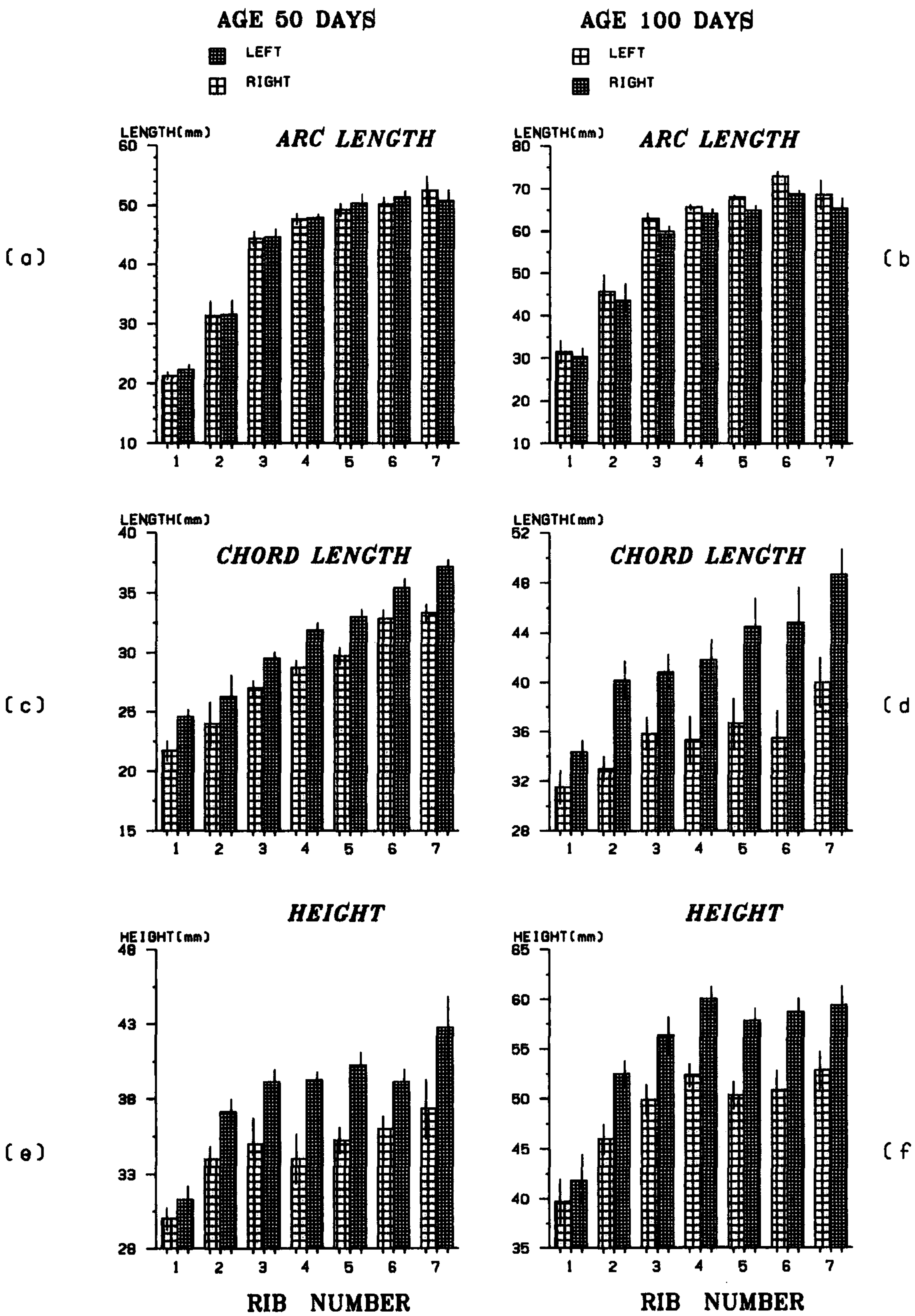
		Age in Days					
		50 Days			100 Days		
		Mean ± SD	F–Ratio	Degree of sig.	Mean ± SD	F–Ratio	Degree of sig.
No. of the Rib							
1st Rib	R	21.29 ± 1.74	0.731	N.S.	31.50 ± 6.50	0.140	N.S.
	L	22.26 ± 2.45			30.25 ± 4.98		
2nd Rib	R	31.31 ± 6.88	0.007	N.S.	45.83 ± 9.39	0.156	N.S.
	L	31.61 ± 6.52			43.67 ± 9.58		
3rd Rib	R	44.36 ± 3.73	0.009	N.S.	63.08 ± 3.14	2.881	N.S.
	L	44.55 ± 4.10			59.92 ± 3.22		
4th Rib	R	47.71 ± 2.76	0.018	N.S.	65.75 ± 1.60	1.400	N.S.
	L	47.88 ± 1.95			64.17 ± 2.86		
5th Rib	R	49.30 ± 3.18	0.311	N.S.	68.25 ± 0.99	6.765	*
	L	50.40 ± 4.59			65.10 ± 2.80		
6th Rib	R	50.24 ± 3.22	0.541	N.S.	73.00 ± 3.03	7.125	*
	L	51.46 ± 2.95			68.92 ± 2.20		
7th Rib	R	52.62 ± 5.59	0.372	N.S.	68.75 ± 8.50	0.328	N.S.
	L	50.83 ± 4.47			65.50 ± 11.00		

D.18–D.24 respectively in appendix D. The overall means with standard deviations of these measurements are given in tables 7.4, 7.5, 7.6, 7.7, and 7.8 respectively.

7.7.2.1 Arc Length of the Ribs

Analysis of variance revealed no significant differences between the right and left arc length of the ribs at age 50 days. However the arcs of the 5th and 6th ribs

FIGURE 7.7 – ARC LENGTH, CHORD LENGTH AND THE HEIGHT OF THE RIBS IN CHICKENS SELECTED FOR PECTORAL ASYMMETRY AT AGE 50 AND 100 DAYS



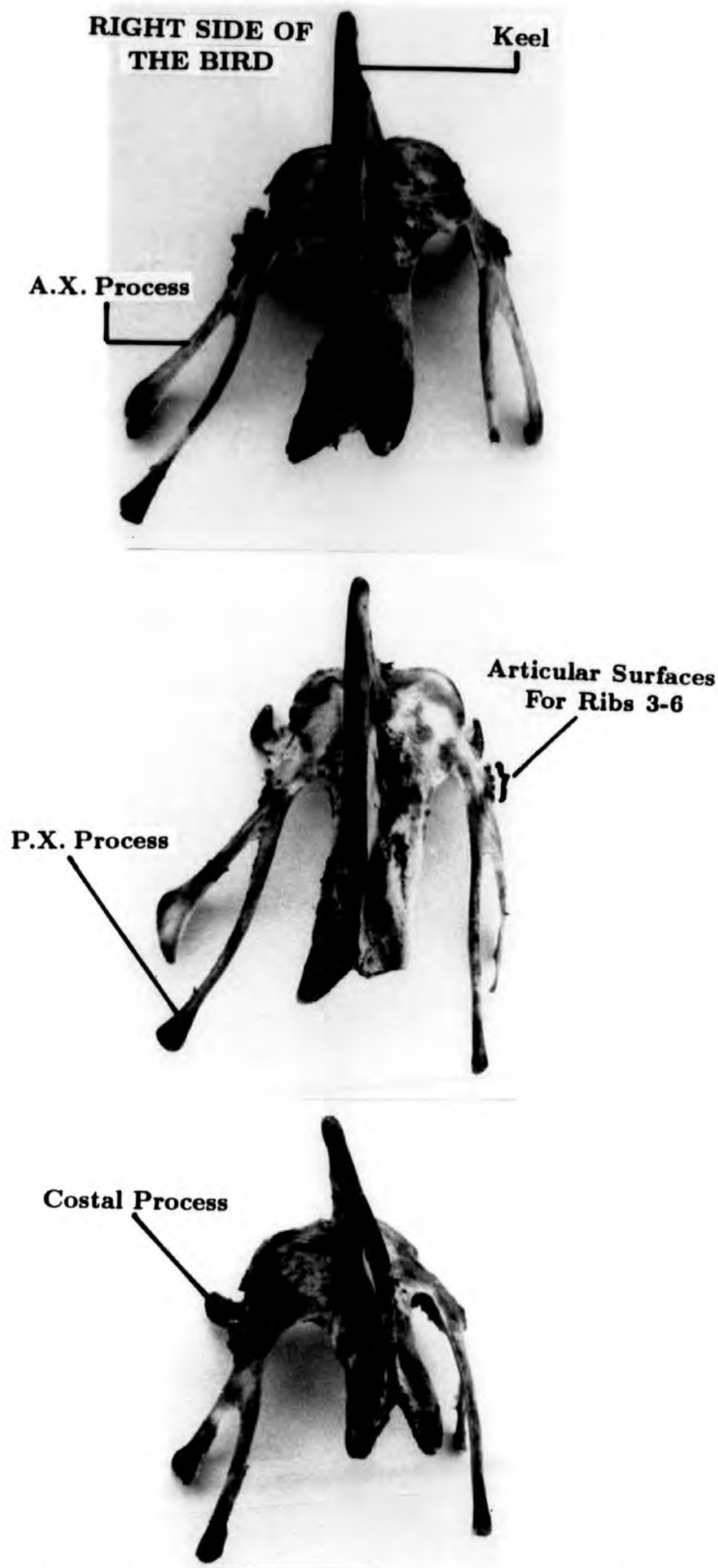


Figure 7.8 – Ventral view of three sternums in the most selected asymmetry birds at age 100 days showing the deformity of the sternum.

PLATE 7.2

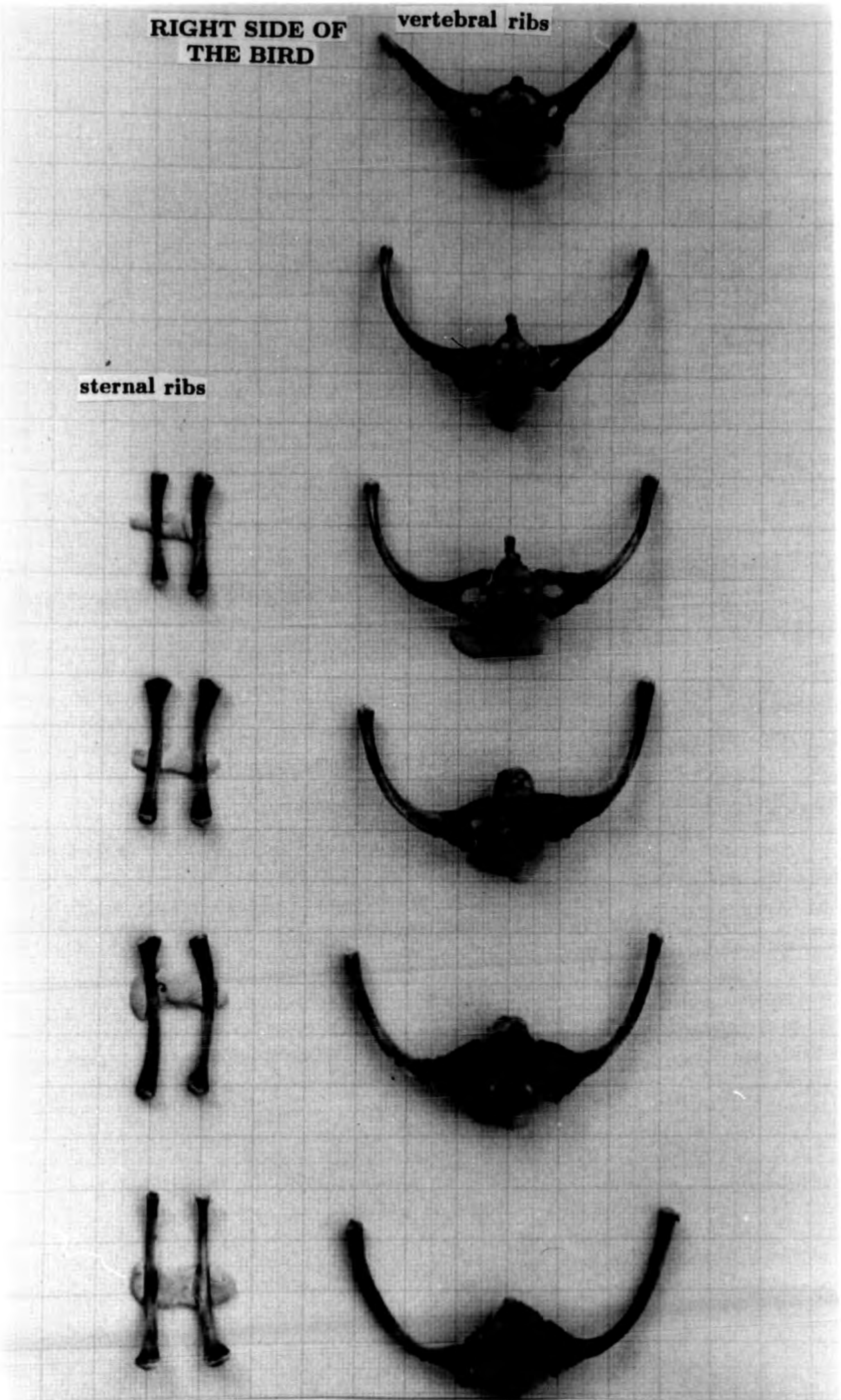


Figure 7.9 – Pairs of vertebral and sternal part of the exarticulated ribs from selected bird at 50 days showing marked asymmetry in the shape of the ribs.

PLATE 7.3

FIGURE 7.10 – ENCLOSED AREA AND THE DORSAL ANGLE OF THE RIBS IN CHICKENS SELECTED FOR PECTORAL ASYMMETRY AT AGE 50 AND 100 DAYS

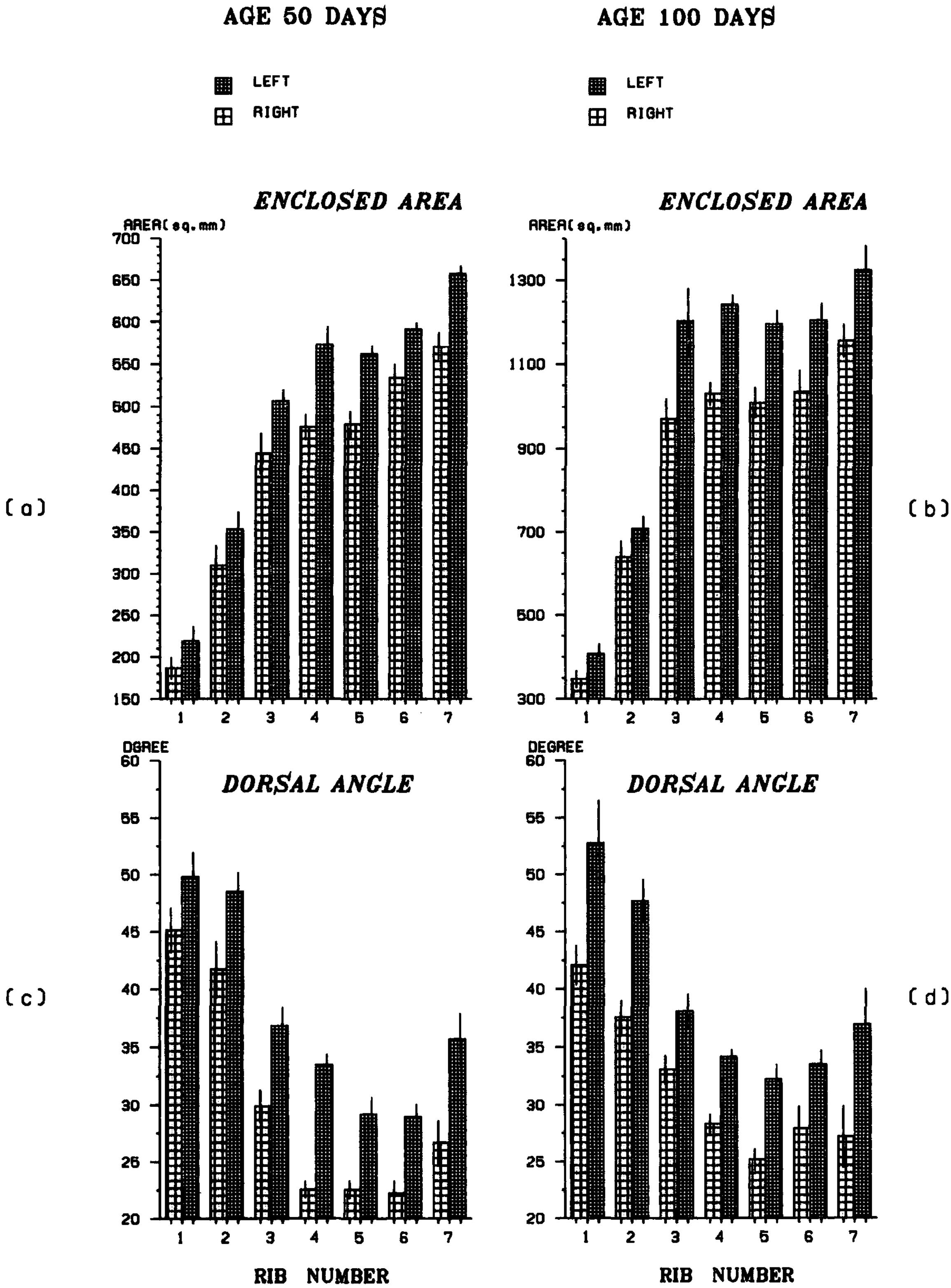


Table 7.5 — Average Chord Length of the Ribs in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

		Age in Days					
		50 Days			100 Days		
		Mean ± SD	F–Ratio	Degree of sig.	Mean ± SD	F–Ratio	Degree of sig.
No. of the Rib							
1st Rib	R	21.71 ± 2.21	7.595	*	31.50 ± 3.33	2.839	N.S.
	L	24.57 ± 1.62			34.33 ± 2.42		
2nd Rib	R	24.00 ± 4.86	0.763	N.S.	33.00 ± 2.53	14.423	**
	L	26.29 ± 4.92			40.17 ± 3.87		
3rd Rib	R	27.00 ± 1.85	7.177	*	35.83 ± 3.25	6.374	*
	L	29.55 ± 1.49			40.83 ± 3.60		
4th Rib	R	28.75 ± 1.75	12.906	**	35.33 ± 4.68	6.665	*
	L	31.88 ± 1.73			41.83 ± 4.02		
5th Rib	R	29.75 ± 2.05	10.658	**	36.67 ± 5.01	6.373	*
	L	32.00 ± 1.92			44.50 ± 5.72		
6th Rib	R	32.86 ± 2.04	5.718	*	35.50 ± 5.43	6.695	*
	L	35.43 ± 1.99			44.83 ± 6.97		
7th Rib	R	33.33 ± 1.86	15.651	**	40.00 ± 5.02	7.897	*
	L	37.17 ± 1.47			48.67 ± 5.65		

at 100 days of age were significantly longer in the left side than in the right one, as shown in table 7.4 and figure 7.7b.

7.7.2.2 Chord Length of the Ribs

Similarly, analysis of variance revealed that the left chord length of all the seven ribs was significantly longer than the right chord length, as shown in the the table 7.5 and figure 7.7c,d.

7.7.2.3 Height of the Ribs

The height of the ribs (mm) from the horizontal line of the vertebral column to the top of the vertebral rib was measured on the graph paper as shown in figure 2.9, plate 2.3.

Analysis of variance revealed that the left ribs had significantly greater height than the right ones at both 50 and 100 days of age, as shown in figure 7.9, plate 7.3 and figures 7.7e and 7.7f respectively.

7.7.2.4 The Enclosed Area of The Ribs

Enclosed area (mm^2) between the right and left rib was calculated on the picture image of the ribs on the graph paper as shown in figure 2.9, plate 2.3. The means with standard deviations of the enclosed area are given in table 7.7, and data plotted in figures figures 7.10a and 7.10b for birds aged 50 and 100 days respectively.

There were no significant differences between the right and left sides of the first and second pair of ribs, whereas for the remaining ribs the left side encloses a significantly larger area at both 50 and 100 days of age.

7.7.3 Extrinsic Measurements on the Ribs

7.7.3.1 The Orientation of the Dorsal Angle of the Ribs

The dorsal orientation angle is the tangent to the rib at the point of articulation between the rib and vertebral column (see figure 2.9. plate 2.3). The data were plotted in figures 7.10c and 7.10d for age 50 and 100 days respectively.

Table 7.6 — Average Height of the Ribs in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

		Age in Days					
		50 Days			100 Days		
		Mean ± SD	F–Ratio	Degree of sig.	Mean ± SD	F–Ratio	Degree of sig.
No. of the Rib							
1st Rib	R	30.00 ± 2.00	1.130	N.S.	39.67 ± 5.68	0.380	N.S.
	L	31.29 ± 2.50			41.83 ± 6.46		
2nd Rib	R	34.00 ± 2.31	6.600	*	46.00 ± 3.63	10.607	**
	L	37.14 ± 2.27			52.50 ± 3.27		
3rd Rib	R	35.50 ± 3.51	5.478	*	49.83 ± 3.87	7.195	*
	L	39.13 ± 2.47			56.33 ± 4.50		
4th Rib	R	34.00 ± 4.72	9.00	**	52.33 ± 2.86	19.739	**
	L	39.25 ± 1.49			60.00 ± 3.10		
5th Rib	R	35.25 ± 2.43	16.471	**	50.33 ± 3.39	16.200	**
	L	40.25 ± 2.49			57.83 ± 3.06		
6th Rib	R	36.00 ± 2.31	6.600	*	50.83 ± 4.79	10.332	*
	L	39.14 ± 2.27			58.67 ± 3.56		
7th Rib	R	37.33 ± 4.84	3.449	N.S.	52.83 ± 4.62	5.604	*
	L	42.75 ± 5.27			59.33 ± 4.89		

Analysis of variance clearly showed that the right side of the rib-cage had a significantly smaller angle than the left side. This is probably due to the right side ribs as being more rounded (curved) than the left ones.

Table 7.7 — Average Enclosed Area of the Ribs in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

		Age in Days					
		50 Days			100 Days		
		Mean ± SD	F–Ratio	Degree of sig.	Mean ± SD	F–Ratio	Degree of sig.
No. of the Rib							
1st Rib	R	186.71 ± 34.90	3.095	N.S.	347.50 ± 49.00	3.747	N.S.
	L	219.57 ± 44.96			407.83 ± 58.55		
2nd Rib	R	309.57 ± 65.63	1.818	N.S.	640.00 ± 98.01	1.784	N.S.
	L	353.29 ± 55.23			707.83 ± 76.59		
3rd Rib	R	443.75 ± 68.03	5.112	*	971.50 ± 116.25	4.976	*
	L	506.13 ± 38.21			1202.33 ± 195.58		
4th Rib	R	475.50 ± 44.11	13.029	**	1031.33 ± 64.56	37.525	***
	L	572.63 ± 62.02			1243.67 ± 55.14		
5th Rib	R	478.63 ± 44.57	20.094	***	1009.83 ± 87.22	13.646	**
	L	562.13 ± 28.09			1195.00 ± 86.42		
6th Rib	R	534.14 ± 42.25	10.656	**	1035.67 ± 126.68	6.239	*
	L	591.43 ± 19.24			1204.00 ± 105.83		
7th Rib	R	570.67 ± 42.00	19.499	***	1156.50 ± 95.90	5.732	*
	L	657.83 ± 23.96			1325.33 ± 143.67		

Table 7.8 — Average Dorsal Orientation Angle of the Ribs in Chickens Selected for Pectoral Asymmetry at Age 50 and 100 Days

		Age in Days					
		50 Days			100 Days		
		Mean ± SD	F–Ratio	Degree of sig.	Mean ± SD	F–Ratio	Degree of sig.
No. of the Rib							
1st Rib	R	45.14 ± 5.19	2.496	N.S.	42.08 ± 4.28	6.544	*
	L	49.79 ± 5.79			52.75 ± 9.27		
2nd Rib	R	41.71 ± 6.59	5.117	*	37.58 ± 3.54	21.565	**
	L	48.50 ± 4.42			47.67 ± 4.69		
3rd Rib	R	29.88 ± 4.09	9.787	**	33.08 ± 3.09	6.470	*
	L	36.81 ± 4.54			38.08 ± 3.69		
4th Rib	R	22.56 ± 2.15	85.647	***	28.33 ± 2.09	29.878	***
	L	33.50 ± 2.56			34.17 ± 1.57		
5th Rib	R	22.56 ± 2.23	14.970	**	25.17 ± 2.34	19.882	**
	L	29.19 ± 4.30			32.25 ± 3.11		
6th Rib	R	22.21 ± 3.01	16.809	**	27.92 ± 4.79	5.713	*
	L	28.93 ± 3.11			33.50 ± 3.13		
7th Rib	R	26.67 ± 4.81	9.226	*	27.17 ± 6.64	5.652	*
	L	35.70 ± 5.47			36.92 ± 7.54		

7.8 Conclusion

The ultrasonic method was very accurate for selecting skeletally asymmetrical birds by measuring the depth of the keel on both right and left sides in live birds. Anatomical measurements confirmed that asymmetrical birds had a significantly deeper keel at the right side, but that the pectoralis muscle at the left side was significantly heavier than at the right side only in birds of 50 days of age and not in other birds, even though the rib-cage had an asymmetrical shape in all measured bones at both 50 and 100 days of age. The most significant measurement on the rib-cage was the breast angle at the left side which was significantly smaller than the right breast angle, while the dorsal angle was significantly larger in the left side than that in the right one. Keel width and the chord length of the ribs were significantly larger at the left side too.

CHAPTER VIII

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DISCUSSION

Intensive selection in poultry during the last few decades has led the modern broiler chicken to have a fast rate of body weight gain and high meat yield. As a result, broiler chickens have about 8-fold greater breast muscle mass than layer chickens at 7 weeks of age, and over 2-fold greater breast muscle mass than their 1972 counterparts (Bulfield, *et al.*, 1988). A high proportion of breast meat muscle is found in the Cobb 500 strain, up to 16.3% of the eviscerated carcass and 38% of the total muscle mass, whereas thigh meat muscle makes 8.9% of the eviscerated carcass (Cobb, 1989a). This recent high increase in proportion of skeletal muscles is a result of increasing the body weight for a given age (Ricklefs, 1985). there is a high genetic and phenotypic correlation between various muscles and between muscle size and total body size (Johnson and Asmundson, 1957). Thus, functional demands on the muscles inevitably change, and consequently modification of structural characteristics of the muscle must ensue to maintain the functional efficiency of the muscles. However, it appears that selection for body weight and breast conformation has resulted in greater increase in breast than in leg muscle and skeletal mass. Perhaps leg muscle weights have lower heritability than breast muscle weights (Johnson and Asmundson, 1957), and have a lower allometric growth coefficient (Swatland 1984). Such disproportionate changes in body parts appears to have contributed to leg and skeletal problems in fast-growing poultry meat lines (Hulan, *et al.*, 1980; Havenstein *et al.*, 1988).

8.1 Live Body Weight

Meat Production from chickens will be valued solely by its mass at a given age. Accordingly, rate of live-weight gain is fundamental to commercial success. As a result, live body weight in the current broiler chicken has been increased dramatically in the last 40 years. The percentage increase in body weight between 1952 and 1989 was shown in table 3.1. In Cobb 500 broilers, body weight has been increased from 2200 to 3500 gram at age 70 days between 1965 and 1990, an increase of about 60% (Cobb, 1989b). In the present study, two groups of broiler chickens were studied, the first group was randomly chosen and called the control group, whereas the second group was selected by a skilled handler at the Cobb Breeding Company. This group was called selected and were thought to show asymmetry in the breast muscle.

If the live body weight of an animal is taken from conception to senescence, the data usually follow a sigmoid, which has the following characteristics: an accelerating phase of growth from hatching, a point of inflexion in the growth curve at which growth rate is maximum, a phase where growth rate is decelerating, and a limiting value (asymptote) of mature weight, towards which the growth curve tends (Wilson, 1977). Indeed the phenomenon of sigmoid growth is not peculiar to chickens but is exhibited by other poultry species, by other animals and by plants.

Most growth equations were developed to model biological processes that underlie growth. Derivations usually began with a consideration of growth rate as some function of the weight achieved, hence

$$\frac{\partial w}{\partial t} = f(w) \qquad 8.1$$

where w is the weight as function of age (t) in the case of interval data. The simplest expressions for f are $f(w) = a$ and $f(w) = a\ w$, which describes exponential growth. Although equations of the type $w(t)$ = a + bt and $w(t)$ = a e^{bt} have been used to describe segments of growth curves, both increase continuously with time and therefore neither provides an adequate description of asymptotic growth. Asymptotic growth equations share the common property that $f(w)$ decrease to zero as the weight approaches the plateau or asymptote. Such functions usually have two terms: one expresses a tendency of the organism to grow and the other expresses factors that restrict growth, hence:

$$\frac{\partial w}{\partial t} = f(w) - g(w) \tag{8.2}$$

The logistic equation (Robertson, 1908) may be expressed as:

$$\frac{\partial w}{\partial t} = aw - bw^2 \tag{8.3}$$

where a is the exponential tendency of weight to increase and b the rate at which this tendency is restricted as weight increases. Accordingly, growth will continue until a = bw, hence the asymptote of the growth equation $w(\infty)$is equall to a/b. equation 8.3 could be re-expressed as the differential equation

$$\frac{\partial w}{\partial t} = aw[\frac{w(\infty) - w}{w(\infty)}] \tag{8.4}$$

which can now be integrated to give

$$\partial w(t) = \frac{w(\infty)}{1 + e^{-kt}} \tag{8.5}$$

which describes the increase over time. The constant a has been replaced by the more familiar k.

This equation (8.5) has three parameters: $w(\infty)$, the asymptotic weight (or other measurements), $w(0)$ the initial weight (hatching weight); and k, the rate constant of the equation whose units are 1/time. Fitting the logistic equation to time-series data yields estimate of the parameters $w(\infty)$ and k, which can be used for comparisons between samples or populations as followed in this study.

Robertson's equation become known as the logistic function and has probably been the most widely used in the study of the growth, although many other functions have been developed in the study of growth such as the equations of Gompertz (1825); Brody (1945); Von Bertalanffy (1957) and Laired (1966). These different equations have been summarized and discussed in some details by Wilson (1977) and Ricklefs (1983).

However, during the commercial growth of meat animals to market weight (market age in the case of the broilers), growth may appear almost linear with a constant rate. For example, in this study up to the slaughter age of the broiler chickens at 49 days, they have a linear growth curve as shown in figures 3.1 and 3.3 with constant growth rate (see figure 3.2). However, selected birds showed heavier body weight at a given age and higher growth rates than the control chickens. Although these selected birds had a higher growth rate than the control birds between their hatching date and 70 days old, as shown in figure 3.3, the two growth rates were similar after this, so that selected birds were still heavier than the controls up to 150 days of age. Since the two groups were reared in the same conditions, this difference in the body weight and early growth rate might be due to the genotype of these selected birds, because the main objective of the selection process in broilers is to increase the growth rate at early ages which has led to a percentage increase in body weight from 171 to 886 during 1952 to 1989 (see table

3.1). This improvement of live body weight is the direct effect of the genetic and nutrition improvements (Summers and Leeson, 1979; Leeson and Summers, 1980).

8.2 Growth of Breast Muscle

In commercial broiler production, breast muscles (pectoralis and supracoracoideus muscles) are obviously important, particularly in respect of the proportion by weight that they form of live body weight and the total meat in the carcass, as mentioned above. However, little attention has been given in the past to the relationship between muscle growth in general and increasing body size. As the latter increases functional demands on the muscle certainly change (Helmi and Cracraft, 1977). But in the consumers viewpoint, they do not know the weight of individual muscles when they select a chicken in a shop. What the consumer sees and probably reacts to is the appearance of muscularity and the way in which the breast muscles bulge outwards over the pectoral girdle. This method of choice prompted the present study, since some individual birds show one side (left) of the breast bulging more visibly than the other (right) and therefore may not have been so attractive to the consumer. I studied pectoralis and supracoracoideus muscles have been studied anatomically and histochemically at various ages, comparing birds thought to have asymmetrical growth with other control birds.

I have examined changes in numbers of each fibre type per square millimeter and in their diameter in both control and selected chickens with age. The main purpose has been to examine the difference(s) between the two sides of pectoralis muscle in control and selected chickens, in addition to compare each side in the control to its corresponding one in the selected chickens.

The absolute values of properties of pectoralis and supracoracoideus muscles, namely their weight, growth rate, proportion to body weight, and degree of asymmetry, did not in general show significant differences between the right and left side either in control or in selected chickens, although some sporadic differences occurred which might reflect sampling effects due the small number of birds in each group. Therefore, following Smith (1980) logarithmic transformation in the allometric growth equation has been used in this study, resulting in linear regressions with high coefficients of correlation. Although logarithmic transformation is not necessarily the best or the only way in which to transform a set of data, as reported by Swatland (1984), it appeared in this study that logarithmic transformation worked well in the allometric growth equation. The results indicated that selected chickens reached their maximum growth rate at 50 days whereas the control chickens did so at 60 days. Furthermore, the general degree of asymmetry at a given age in pectoralis muscle was significantly greater in selected chickens than in the controls. On the other hand supracoracoideus muscles increased in weight by a constant proportion of live weight with age. This increase was in agreement with the results of Moran (1977) and Swatland (1979a) in broilers and turkeys, respectively.

Allometric growth coefficients of all parameters measured on control and selected chickens were compared between each side in the control and the corresponding one in selected chickens. It appeared that the pectoralis and supracoracoideus muscles were growing faster than the growth in total body weight since their allometric growth coefficient against body weight were significantly different from one. However, no significant differences were obtained between the two sides in control or in selected chickens, nor between each side of the control and its corresponding side in selected chickens. As a result, pectoralis muscle was growing at a similar relative rate in both groups; although the right pectoralis muscle in selected chickens was relatively smaller than its corresponding one in control chickens. Growth in weight of the pectoralis muscle was closely matched to growth of the supracoracoideus muscle with b = 0.963 and b = 0.956 in control, and b = 1.00 and b = 1.01 in selected chickens, for the right and left sides respectively. Swatland (1979b) reported a similar match in the growth of the right supracoracoideus muscle to the whole pectoral muscle group (pectoralis, supracoracoideus and coracobrachialis) with b = 1.02 and 1.00 in turkey males and females respectively.

Allometric growth coefficients of breast muscle weight against many different skeletal bones measurements (length and weight) were calculated, following a similar study by Asmundson and Lerner (1942). None of these allometric growth coefficients was different between the two sides in control or selected chickens (see tables 3.10, 3.11, and 3.16).

8.3 Architecture of Pectoralis Muscle

Mature avian skeletal muscle fibres are broadly classified as fast-twitch glycolytic (FG, or white), fast-twitch oxidative- glycolytic (FOG, or Intermediate), and slow oxidative/tonic (SO or red) (George and Naik, 1958; Talesarea and Goldspink, 1978; Maier, 1983; Rosser and George, 1984; Johnston, 1985; and Rosser and George, 1986b), although a variety of synonyms and subtypes are currently in use (Chiasson and Goulet, 1984; Shafiq *et al.,* 1984; Suzuki, *et al.*, 1985). The histochemical characteristics of the various fibre types have been correlated with their physiological characteristics and contractile properties (see Melichana *et al.*, 1974; Gauthier *et al.*, 1983; Morgan and Proske 1984). Fibre-type distribution in the avian pectoralis muscle is based upon a limited amount of tissue in a few published reports. However, these reports have never described the distribution of fibre types throughout the belly of the pectoralis muscle for any one species (see Rosser and George, 1986b). Furthermore, there are still substantial gaps in the understanding of the structure and function of avian muscle-fibre types and in particular the slow fibres (SO) (see Shafiq *et al.*, 1984; Suzuki *et al.*, 1985; Rosser and George 1986b; Rosser *et al.*, 1986). The fibre architecture of pectoralis muscle, the largest of the avian flight muscles, is complex and its origin is extensive (Papa and Lyon, 1989), whereas the internal arrangement of the fibres is not readily characterized in textbook terms (Raikow, 1985). The fibres proceed craniodorsally from the sternal origin of the muscle and cranioventrally from the large caudolateral fasciculus (Hudson and Lanzillotti, 1964), converging onto an aponeurotic extension of the tendinous insertion attaching the muscle to the humerus. These general characteristics appear to give the muscle a modified bipennate (Vanden Berge, 1979).

The complex anatomy of the pectoralis muscle has been deduced, at least in part, from observation of postmortem complexity in the conversion of this muscle to meat in broiler chickens (Papa and Lyon, 1989). This complexity is the consequence of intensive selection for size or growth rate which resulted in increased muscle weight and myofibre number in the chicken (Smith, 1963; Mizuno and Hikami, 1971) and quail (Fowler *et al.*, 1980). The relationship between muscle size and myofibre diameter in selected animals is not clear. Some workers (Smith, 1963; Luff and Goldspink, 1967; Byrne *et al.*, 1973; Hanraham *et al.*, 1973; Swatland 1980) reported that greater myofibre diameter in selected animals contributed to greater muscle weight, but in other studies, myofibre diameter was not affected by selection (Aberle and Doolittle, 1976) or myofibres of only one type showed hypertrophy in selected lines (Fowler *et al.,* 1980).

In my study, the main objectives were to determine muscle fibre type and diameter in two different locations within the pectoralis muscle in both control and selected chickens.

8.3.1 Muscle Fibres

It is difficult to be certain that all the fibres will appear in a given cross-section, even in muscles where the fibres appear to lie parallel to the long axis of muscle (Timson, *et al.,* 1985), Also, the percentage of the actual fibre number that will appear in a cross-section of a muscle varies from muscle to muscle (Nicks *et al.,* 1986), therefore interpretation of fibre number comparisons between two muscles using this method is difficult at best (Timson, *et al.,* 1989). In my study, great care was always taken to ensure that the strips of tissue were taken from similar places to avoid any intramuscular variation in diameter and number of fibre types. Moreover, the mean of fibre number per square millimeter was taken from all microscopic fields throughout the muscle belly thickness. The concept of an indicator for fibre number is suggested by Stickland and Goldspink (1973), and has been supported by Timson *et al.,* (1989), namely that the relative fibre number of any muscle is a good predictor (indicator) of the total fibre number of the same muscle in another animal. (The relative fibre number means a given muscle of an animal compared to the fibre number of the same muscle in a different animal). In this study differences in the fibre number and diameter with age were investigated. Comparisons were made between the two sides in each bird, and between each side in the control and the corresponding side in the selected chickens. In addition a comparison was made between two different locations (A and B) representing the anterior and mid part of the pectoralis muscle.

In the chicken, the pectoralis muscle consists almost entirely of fast-twitch fibre types, whereas the slow fibres are of extremely rare occurrence. Furthermore, when slow fibres are present they are limited in number and restricted to one small area at the deep side of pectoralis muscle. This small area has been called the deep red region by Gauthier and Lowely (1977) and comprises about 1% of the total pectoralis muscle weight in the adult chicken (Rosser, *et al.*, 1986). Moreover, there is a very significant difference in the occurrence of the SO fibres between the deep red region and the superficial part of the pectoralis muscle as reported by Rosser and George (1986b). In my study, the mean fibre-number per square millimeter and mean diameter were calculated from all the microscopic fields throughout the muscle belly including the small red region. However, there was very clear evidence that the red region consists of large numbers of slow fibres.

Absolute fibre number in region B was significantly greater for white fibres than in region A, whereas numbers of red and intermediate fibres in region A were greater than in region B in both control and selected chickens. These differences are in agreement with Chandra Bose and George (1965); and Rosser *et al.*, (1986a,b) that the anterior part (region A) consists of more red and intermediate fibres than the posterior and mid part of the pectoralis muscle. Thus, it appears that the fibres in region A are better adapted for aerobic metabolism and capable of greater sustained activity than those in region B. Moreover, the percentage of white fibres per square millimeter in region A increased with age from 88.40 to 94.64% and 84.23 to 87.14% in control and selected chickens respectively, whereas the percentage of red fibres number decreased in both groups. Transformation of fibre types has been reported by Aberle and Stewart (1983), when they compared two strains of chickens, the layer- and broiler-type chickens. They found there was a higher proportion of red fibres (SO) in broiler-type chickens than layer birds at the same age. This was also the case for my selected chickens which had a higher proportion of red fibres throughout all ages studied (see tables 4.4 and 4.8) than the control chickens. Moreover, transformation of fast-twitch (FG and FOG) to slow-twitch (SO) types was found by an increase in the frequency of red (SO) fibres during the growth of layer chickens, and it was also observed that the decline in intermediate-fibre (FOG) frequency was greater than the increase in frequency of type FG fibres in layer chickens (Aberle and Stewart, 1983); swine (Davies, 1972; Swatland, 1975); sheep (White, *et al.,* 1978); cats (Tomanek, 1975); and rats (Brooke, *et al.,* 1971).

In the present study the percentage of white fibres was smaller, and the percentage of red fibres was greater in region A of the selected chickens than in the controls at all ages studied. The differences and the transformation of fibre type might be explained by genetic control (Robbins, *et al.,* 1982; Periasamy, *et al.,* 1984a; Periasamy, *et al.,* 1984b; Rushbrook and Somes, 1985); or it could be related to functional demands on skeletal muscle, related to body weight, which have a direct effect on the rate of myofibre type differentiation (Aberle and Stewart, 1983). Moreover, in my study, the percentages of each fibre type were calculated from numbers per square millimeter; therefore fibre-type diameter could affect the number of fibre types. Consequently the differences in the percentage of the pectoralis muscle fibre types between the control and selected chickens might be due to that reason, since the white- and red-fibres in selected chickens were significantly larger in diameter (and had significantly larger allometric growth coefficients) than in control chickens.

The results of statistical comparison between the two sides of pectoralis muscle revealed that there were no significant differences in the absolute values of the fibre number (per square millimeter) either in control or selected chickens. This result indicated that the structure of pectoralis muscle was symmetrical within each group of chickens, and not affected by the apparent asymmetry of the breast muscles in the selected chickens. However, white- and red-fibres numbers in the left muscle (region A) in selected chickens had significantly larger allometric growth coefficients against body weight and pectoralis muscle weight than in the right side. These large allometric growth coefficients in selected chickens indicate that white- and red-fibre numbers per square millimeter were decreasing faster in the left than in the right side. Moreover, these allometric growth ratios were also significantly larger than the corresponding ones in the control chickens. Thus the number of white and red fibres in the left pectoralis muscle of the selected chickens were decreasing faster than the corresponding fibres in the control chickens. This rapid decrease in fibre number per unit area might be due to their absolute number or diameters, since the fibre number was calculated per square millimeter (see the next section). Since greater body weight is indicative of an increased muscle mass, as has been widely reported (Fowler, 1958; Bailey, *et al.,* 1960; Biondini, *et al.,* 1968; Harbison, *et al.,* 1976); many investigators have focussed on muscle characteristics (fibre number and fibre size) as they relate to muscle growth and development (Smith, 1963; Robinson and Bradford, 1969; Hanrahan, *et al.,* 1973; Ezekw and Martin, 1975; Martin, *et al.,* 1979; Fowler, *et al.,* 1980); however, for the most part, these studies have supported the concept that muscle-fibre number is highly correlated with muscle size (Aberle and Doolittle, 1976; Luff and Goldspink, 1970); whereas muscle fibre diameter is not as highly correlated to muscle size (Hooper, 1978; McCarty and Shiel, 1975). The main reason for this correlation between body weight and each of the fibre numbers and diameters is that the numbers of fibres are determined prior to hatching (in birds), at which time environmental variation is normally very low. In addition, fibre number is determined largely by additive gene action (Smith, 1963). On the other hand, environmental variation is expected to markedly affect fibre size, thus lowering heritability of this trait (Hooper, 1978), whereas the total muscle fibre-number remains constant postnatally (Staun, 1963; Stickland and Goldspink, 1973). However, McMeekan (1940 and 1941) working with swine and Joubert (1956) with four species of mammals (rabbit, swine, sheep, and cattle) found highly significant positive correlation between mean muscle-fibre diameter and body weight, which is in agreement with the result of this study especially for white and red fibres.

8.3.2 Fibre-Type Diameters

The measurement of muscle-fibre diameters is not necessarily a good method of predicting muscularity in cattle (Tuma, *et al.,* 1962) and pigs (Livingston, *et al.,* 1966). The basic problem is one of separating the greater muscle girth associated with superior muscularity at a given age from the progressive increase in muscle girth which occurs in all farm animals during growth. Thus, having correlated statistically for body-size differences in a group of animals at the same live weight, the residual differences in fibre diameters associated with differences in muscularity may be small and lost amid sampling errors, changes in fibre diameter due to excision, and histological processing (Swatland, 1980). Furthermore, there is always a possibility of superior muscularity being due to increased numbers of muscle fibres, or longer fibres overlapping in the belly of a longer muscle. None of these sources of greater muscularity need necessarily cause any increase in muscle-fibre diameter (McCarty and Shield, 1975; Hooper, 1978; Swatland, 1980). However, in broiler chickens, although large-bodied birds had larger and greater numbers of muscle fibres at broiler age than did smaller-bodied birds, fibre size (diameter) was apparently of greater importance in determining muscle size (Smith, 1963; Luff and Goldspink, 1967; Byrne, *et al.,* 1973; Hanrahan, 1973; Aberle and Stewart, 1983). The latter authors concluded from their studies on broiler chickens that more rapid growth and greater muscularity of broiler-type birds are caused by more rapid myofibre hypertrophy and presence of more myofibres. They suggested that selection for growth and muscularity favours factors that promote selective radial growth (hypertrophy) of white and intermediate type myofibres, as in broiler-type chickens.

In the present study, fibre-type diameters were measured in two locations, A and B, representing the anterior and mid- part of the pectoralis muscle in both control and selected chickens. There was clear evidence that fibre diameters were significantly greater in the anterior (region A) than in the mid part (region B) of the pectoralis muscle, in both white and red fibres. All fibre types had a similar allometric growth coefficient (diameter growth against body or muscle weight) within each group of chickens. However, in selected chickens, white fibres had a significantly larger allometric growth coefficient in region A of both left and right pectoralis muscles than the corresponding sides in controls. Also white and red fibres in region A of the left pectoralis muscle grew faster in absolute diameter than in the controls.

Significant differences in fibre diameter between two locations within the pectoralis muscle of chickens have been reported by Smith and Fletcher (1988), but their results revealed that white-fibre diameters in the anterior section were significantly smaller than in the posterior at age 50-55 days, and they did not detect any significant differences in the number of each fibre type per unit area; also they reported that red fibres did not exist, AND only one intermediate fibre was found in the pectoralis muscle of the three broilers chickens they studied. However, in my study red and intermediate fibre type were observed very clearly, with meaurable percentage occurrences in both regions. In order to compare the result of my study with those of Smith and Fletcher (1988) for birds of age 50 days the following figures, taken from both control and selected chickens at the same age, are relevant. The occurrence of red fibres was 2.92% and 2.41% for the right and left region A in control chickens, and 8.78% and 3.43% for the selected chickens. (In region B, the occurrence of red fibre was very much less than these values). Also the intermediate fibres were higher in their occurrence than the red fibres, 8.43% and 8.76% in the right and left region A in the control chickens, and 7.68% and 7.63% in the selected chickens, whereas in region B, the intermediate fibres were less, 5.72% and 5.26% in controls and 2.28% and 3.25% in selected birds. In a similar study, Kiessling (1977) reported a ratio of 96% white, and 4% red fibres in broiler pectoralis muscle, and a range of 90 to 100% white and 0 to 10% intermediate fibres in turkey breast muscle. These apparent differences in percentage occurrence of fibres in pectoralis muscle might be due to two main reasons. Firstly, the differences between strains, whether they are broiler or layer chickens, is related to their genetics. The modern broiler contains greater numbers of fibres and the proportion of white fibres increases and of intermediate fibres decreases during body growth (Aberle and Stewart, 1983). Secondly, the differences could be due to the different locations of the tissue samples, especially how close they are to the deep side (close to the sternum) of the pectoralis muscle, because Suzuki (1978) showed that the superficial area of pectoralis muscle was composed of over 99% white fibres (with the rest being intermediate), whereas the deeper region closer to the sternum, contained 54% intermediate fibres, only 17% white fibres and 29% red fibres. Suzuki's results were based on deep samples taken from broilers and young layer-type birds at 6 weeks old and from superficial samples from older adults birds; moreover, the superficial samples were taken from the middle portion of the pectoralis muscle, whereas the deep samples were taken from the anterior region of the muscle. This could partially explain the differences in percentage occurrence of the red and intermediate fibres in different studies on the pectoralis muscle.

In summary, pectoralis muscle is composed of heterogeneous population of fibres which are very differently distributed through the muscle belly. The posterior and mid part of the pectoralis muscle consists primarily of white fibres and very rare occurrence of slow fibres. However, red fibres are almost dominant in the deep region of the anterior side of the pectoralis muscle, therefore Gauthier and Lowey (1977) defined the pectoralis muscle as having two regions, white and red.

8.4 Avian Skeleton

The avian skeleton has become simplified in comparison to that of the mammals. The skeleton is specialized for lightness and for strength in flying birds. Reduction in the bone marrow and its replacement by extensions of the air-sac system from the lungs decrease the weight of vertebrae, the pelvis, and certain of the long bones in most bird families. Many avian bones become pneumatic (Wise, 1975), whereas the strength is attained by the structure of the bones and by the fusion of the main bones of the skull and pelvis. Fusion of several dorsal (back) vertebrae also occurs in some birds. There is a fusion and a consequent reduction in numbers of carpal, metacarpal, tarsal, and metatarsal bones. Despite this fusion, however, the bird skeleton is not a rigid framework (George and Berger, 1966).

Direct selection for increased amount of breast muscles and total body weight at a given age causes the relative weight of the skeleton of poultry to decline with age (Clayton, *et al.,* 1978; Bacon, *et al.,* 1986; Nestor, *et al.,* 1987). Thus at equal body weights, the skeletal system may be less mature in fast-growing broilers, which have been selected on the basis of meat yield, than in layers (Swatland, 1984). As a result of this intensive selection, poultry are afflicted by a number of genetic skeletal defects presumed to have a genetic bases (Wise, 1975; Riddle, 1975; Reiland, et al. 1978; Swatland, 1984), For example, Swatland (1984 and 1990) suggested that asymmetrical or abnormal development of the sternum in broilers at market weight might have a genetic cause, but did not propose a mechanism linking the genotype and the abnormal phenotype. Also, several authors have identified abnormal long bone torsion (rotation) as a cause of lameness in domestic poultry (poulos, et al. 1978; Randall and Mills, 1981; Riddell, 1981; Duff and Thorp, 1985a). Duff and Thorp (1985b) identified this skeletal defect as a pathological expresion of normal growth process.

In my study, length and weight of many skeletal bones were measured at different ages in both control and selected chickens. The absolute values showed no significant differences either between the two sides in the control or selected chickens, or between each side in control: to corresponding ones in the selected chickens. However, regression analysis of these measurements against body weight revealed some significant differences in the allometric growth coefficient.

Total keel length in control chickens had significantly larger allometric growth coefficient than in the selected chickens, whereas the allometric growth coefficient of the length of the boney part of the keel was smaller. Thus the main difference was due to the absolute cartilaginous keel length which was longer in the control than in selected chickens. This may be due to the degree of the osteogenesis. On the other hand, although the bone-keel length was not significantly different between the two groups, the total keel weight in control chickens was grew faster than in selected chickens.

One of the significant differences between the two groups of chickens was found in the posterior xiphisternal process (PXP). Although the absolute PXP length did not show significant difference between the two sides of the control or selected chickens, or between the two groups of chickens; the allometric growth coefficient of PXP length against body weight was significantly different from the value expected (0.333) in both groups. Indeed, the allometric growth coefficient in control chickens was significantly larger than in selected chickens. Furthermore, the slopes were not parallel ($p < 0.05$), which indicated that PXP length in control chickens was growing faster than in the selected chickens; hence relative to body weight, it was longer than the PXP length in selected chickens.

Similar results were obtained for the coracoid bone length: the control chickens had a longer coracoid that was growing in length faster than in selected chickens. Also, the weight of the coracoid bone in control chickens was heavier and grew faster than in selected chickens.

No significant differences were obtained for the clavicle bone weight between the two groups of chickens, but the left side of the clavicle bone in selected chickens had a significantly smaller allometric growth coefficient against body weight, than its corresponding one in the controls.

The most important result in the present study concerned the shape of the rib-cage and the depth of the keel in relation to changes in shape and muscle distribution in the surrounding carcass. Some years ago, Johnson and Asmundson (1957) ventured the opinion that the objectives of some selection programmes with poultry were somewhat ill-defined, in not making clear whether the ideal was a pleasing conformation, a relatively larger amount of meat, or both. In modern turkeys, for example, there is a decreasing correlation between sternum depth and breast muscle weight. This low correlation between sternum depth and breast muscle weight (0.33 and 0.46 at 24 weeks in male and female, respectively) was of little interest and was excluded from the recommendation made in their conclusion. However, later on, Swatland (1979a) confirmed Johnson's and Asmundson's (1957) result and concluded that the impression of meat depth gained by visual examination of the carcass would be proportional to the meat depth but inversely proportional to the keel depth. This result was tested with the selected chickens in my study that showed the most asymmetrical appearance in the breast muscles.

The shape of the rib-cage, and the depth, height, and width of the keel in the most asymmetrical selected (MAS) chickens were used (see chapters V and VII). These MAS chickens were selected by an ultrasonic device. They showed different breast depth on each side of the keel in live birds. They also showed an apparent difference (asymmetry) in the shape of the breast muscles. The left pectoralis muscle weight was significantly heavier ($p < 0.05$) than the right muscle at 50 days of age, but not at 100 days, although the degree of asymmetry as measured by relative muscle mass, in these birds was high at both ages (94.47% and 90.61%, respectively as shown in table 7.2). The proportion contributed by the pectoralis muscle to live body weight was significantly smaller ($p < 0.05$) on the right side at age 50 days but not at age 100 days, although the degree of asymmetry was 91.53% and 92.29%, respectively (see table 5.3). Furthermore, for some additional measurements on the pectoralis muscle including thickness (at the anterior part), length, width, and the longest and shortest fascicle in the pectoralis muscle; the left pectoralis muscle had significantly greater values than the right side (see table 7.2). Thus as shown in tables 5.3 and 7.2, the apparent asymmetry in the selected chickens was not necessarily related to the weight of the pectoralis muscle as shown in table 5.6 which revealed that pectoralis muscle weight from all the studied birds (control and selected birds) were normally distributed as shown in figure 5.12.

Furthermore, the shape of the rib-cage and keel were studied in these MAS chickens. Keel depth and the breast angle were the most important parameters of the keel and rib- cage shape measurements. Keel depth in the MAS chickens was very significantly different on both sides of the keel. The right side of the keel was very significantly deeper either in live birds by ultrasonic measurement (see table 7.2), or by direct measurements (tables 5.5 and 7.3), whereas the keel width and keel height were significantly greater in the left side. On the other hand, breast angle was very significantly larger at the right side of the rib-cage which indicated some kind of asymmetry of the rib-cage in these MAS birds. Therefore the shape of the ribs was studied by taking the following measurements of the ribs on both sides of MAS chickens: arc and chord length, height, enclosed area, and the orientation dorsal angle. Statistical analysis revealed that the left side of the rib-cage (which appeared visibly higher than the right side) had significantly greater values of these measurements than the right side. Thus, these results revealed that the left keel in these MAS birds was shallower and had greater width than the right side, whereas the left rib-cage had smaller breast angle but greater dorsal angle. Moreover, the left ribs appeared to be greater in value for the arc, chord, enclosed area and the height of the ribs (see tables 7.4 to 7.8).

The present study revealed that the asymmetrical appearance of the pectoralis muscle, with a more bulging breast on the left side in some individual birds, was due to the shallow keel at that side and deeper keel in the other side. This result supports the assumption made by Swatland (1979a), that the perception of the actual meat depth is modified by the extent to which the meat depth bulges or assumes a convex profile lateral to the keel. Therefore, the depth of the actual amount of breast meat would be enhanced in appearance by the relatively slow growth in keel depth (Swatland, 1979a).

Besides the above results, which showed the relationship of the breast muscle appearance to the keel depth, there were differences in the rib-cage and keel depth between the two sides of the sternum within a bird. This indicated some kind of deformation in the skeletal system in these individual birds. Skeletal problems in fast growing poultry meat lines have been widely reported in recent years (Reiland, et al., 1978; Nestor, *et al.,* 1987; Nestor, *et al.,* 1988). This problem has arisen from the direct selection for increased amount of breast muscles and total body weight in meat-type chickens. High growth rate in broiler chickens has made the skeletal system significantly less 'mature' in both quantitative and qualitative terms, than that of laying strain birds at equal body weights (Wise, 1970a), (Qualitative studies included the histology and bone ash, density and strength; whereas the quantitative aspects related bone weight to body weight; Wise, 1970a). As a result, deformations in the skeletal system have been referred by many investigators to the influence of genotype (Riddel, 1973; Wise. 1973; Hulan, *et al.,* 1980, Swatland, 1984). Heavy body weight and increased size of the breast muscles, achieved by intensive selection for faster growth rate regardless of the growth of the skeleton has caused severe damage to the poultry carcass especially to the legs (Marsden, 1940; Miller, 1968; Clayton, *et al.,* 1978; Nestor, *et al.,* 1987; Nestor, *et al.,* 1988). Similarly, the asymmetrical shape of the rib-cage deformation in my MAS birds, could be due to the imposition of abnormal loods due to fast growth of body weight and muscle weight while the ribs are still maturing, causing a pathological expresion of an underlying normal asymmetry as seen by Palsson and Vergers, (1965) in sheep.

As a result of the skeletal-system deformation in the modern broiler chickens, the concept of skeletal growth or 'frame size' and its relationship to the overall rearing programme has become a much discussed topic within the poultry industry during the past few years (Quarles, *et al.,* 1981; Vint, 1984; Nestor, *et al.,* 1988; Lilburn, *et al.,* 1989; Dekalb, 1990a,b). Moreover, the growth parameters such as body weight, shank length and/or width, and back length do appear to have a significant relationship to economically important laying-house-performance traits (Vint, 1984).

8.5 Conclusion

Although direct selection has increased both breast muscle and total body weight at marketable age of broiler chickens, the rate of skeletal growth has not increased proportionally and has led to many skeletal problems in the current types of fast growing broiler chickens. The asymmetrical shape of some individual broilers I studied was due to deformity of the keel and rib-cage shape, which caused the left side of the chickens' breast to bulge more than the right side. This asymmetry in the rib-cage may be a pathological expression of a normal growth process caused by intensive selection. However, more investigation is needed to find out why the asymmetry is always in the same direction, and what is the relationship between the direction of this asymmetry and asymmetry in other parts of the body.

On the basis of these results, I fully support the suggestion made by Wise (1973), that the incidence of deformed skeletons is due to the influence of genotype and therefore that the restriction of early growth, regardless of subsequent growth rate could greatly reduce the expression of the problem. Moreover, I suggest that the skeletal growth concept should be investigated more fully to compare its relationship to the commercial economical traits and to include this relationship in the selection indices for the breeding programme of the broiler chicken.

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APPENDICES

APPENDIX A

APPENDIX A

COMPUTER PROGRAM 1

A.1 - Number of Fibre Types in Square Millimeter

```
10 REM THIS PROGRAM IS (NOFIB1) TO CALCULATE THE NUMBER OF
   FIBRES/SQ.MM
20 REM VERSION1
30 PRINT "THIS PROGRAM IS (NOFIB1) TO CALCULATE THE NUMBER OF
   FIBRES/SQ.MM
40 INPUT "THE TITLE OF THE RUN ?" NAME$
50 INPUT "THE NO. OF READING ?" S
60 INPUT "THE FIELD DIAMETER ?" N
70 M=((N*0.01)/2)^2)*3.14115927
80 DIM A(S), B(S), C(S), TT(S), X(S)
90 FLAG=1
100 GOSUB 500
110 I=1
120 FOR I=1 TO S
130 A(I)=X(I)*M
140 NEXT
150 EA=E: DA=D: SDA=SD: SEA=SE: CVA=CV
160 FLAG=2
170 GOSUB 500
180 I=1
190 FOR I=1 TO S
200 B(I)=X(I)*M
```

```
210 NEXT
220 EB=E: DB=D: SDB=SD: SEB=SE: CVB=CV
230 FLAG=3
240 GOSUB 500
250 I=1
260 FOR I=1 TO S
270 C(I)=X(I)*M
280 NEXT
290 EC=E: DC=D: SDC=SD: SEC=SE: CVC=CV
300 FLAG=4
310 GOSUB 500
320 I=1
330 FOR I=1 TO S
340 TT(I)=X(I)*M
350 NEXT
360 ETT=E: DTT=D: SDTT=SD: SETT=SE: CVTT=CV
370 *FX6
380 VDU2
390 PRINT NAME$
400 I=1
410 FOR I=1 TO S
420 PRINT I"-"; "T1="; A(I), "T2="; B(I), "T3"; C(I), "TOTAL="; TT(I)
430 NEXT
440 PRINT "TOTAL1 T1="; EA, "T1AV="; DA, "T1, SD="; SDA, "T1,SE="; SEA,
    "T1,CV="; CVA
450 PRINT "TOTAL2 T2="; EB, "T2AV="; DB, "T2, SD="; SDB, "T2,SE="; SEB,
    "T2,CV="; CVB
460 PRINT "TOTAL3 T1="; EC, "T1AV="; DC, "T3, SD="; SDC, "T3,SE="; SEC,
    "T3,CV="; CVC
470 PRINT "TOTAL TT="; ETT, "TTAV="; DTT, "TT, SD="; SDTT, "TT,SE=";
    SETT, "TT,CV="; CVTT
480 VDU3
490 END
500 E=0: I=1
```

```
510 FOR I=1 TO S
520 IF FLAG=4 GOTO 610
530 IF FLAG=3 GOTO 590
540 IF FLAG=2 GOTO 570
550 PRINT "NO. T1( ";I;" )"
560 GOTO 630
560 PRINT "NO. T2( ";I;" )"
580 GOTO 630
590 PRINT "NO. T3( ";I;" )"
600 GOTO 630
610 X(I)=A(I)+B(I)+C(I)
620 GOTO 640
630 INPUT X(I)
640 X(I)=X(I)/M
650 E=E+X(I)
660 NEXT
670 D=E/S
680 I=1: K=0
690 FOR I=1 TO S
700 G=(X(I)-D)∧2
710 K=K+G
720 NEXT
730 SD=(K/(S-1))∧0.5
740 SE=SD/(S∧0.5)
750 CV=SD*100/D
760 RETURN
770 END
```

COMPUTER PROGRAM 2

A.2 - Diameter of Fibre Types μ m

```
10 CLS
20 REM THIS PROGRAM IS TO CALCULATE THE DIAMETER OF FIBRE TYPES
30 REM VERSION 2
40 PRINT "THIS IS (D2) TO CALCULATE THE DIAMETER OF FIBRE TYPES"
50 INPUT "INPUT THE DATE ? " DATE$
60 INPUT "INPUT THE FILE NAME ? " FILE$
70 INPUT "THE TITLE OF THE RUN ?" NAME$
80 INPUT "THE MAGNIFICATIN ?" M
90 INPUT " THE MAXIMUM NUMBER OF READING ?" S
100 DIM A(S,5), B(S,5), R(S,5), MAXN(5), AV(5), G(5), H(5), L(5)
110 I=1
120 FOR I=1 TO 5
130 PRINT "NO. OF THE READING FOR TYPE (";I;")"
140 INPUT MAXN(I)
150 NEXT
160 FOR Z1=1 TO 5
170 IF MAXN(Z1)=0 THEN 550
180 PRINT SPC(10) "****TYPE(";Z1;")****"
190 FOR I=1 TO MAXN(Z1)
200 PRINT I"-" SPC(2)" (X1,";I")"
210 INPUT A(I,Z1)
220 IF A(I,Z1) <=0 THEN VDU7:PRINT" THERE IS NO D<=0": GOTO 200
230 PRINT I"-" SPC(2)2 (X2,";I;")"
240 INPUT B(I,Z1)
250 IF b(I,Z1) <=0 THEN VDU7:PRINT" THERE IS NO D<=0": GOTO 230
260 R(I,Z1)=(A(I,Z1)+B(I,Z1))*M/2
270 NEXT I
280 REM CORRECTION THE DATA
290 INPUT "DO YOU WISH TO COOECT THE DATA ? (Y/N)" COR$
300 COR$="N" THEN GOTO 410
310 COR$ < > "Y" THEN VDU7: GOTO 290
```

```
320 INPUT "THE DATA NO. TO BE CORRECTED" K
330 PRINT "DIAMETER X1-"; K
340 INPUT A(K,Z1)
350 PRINT "DIAMETER X2-"; K
360 INPUT B(K,Z1)
370 (K,Z1)=(A(K,Z1)+B(K,Z1))*M/2
380 INPUT "DO YOU NEED TO CORRECT ANY MORE DATA (Y/N)" CORR$
390 IF CORR$="Y" THEN 320
400 IF CORR$ < > "N" THEN VDU7: GOTO 380
410 REM LOOP FOR STATISTICS
420 C=0:I=1
430 FOR I=1 TO MAXN(Z1)
440 C=C+R(I,Z1)
450 NEXT
460 AV(Z1)=C/MAXN(Z1)
470 F=0:I=1
480 FOR I=1 TO MAXN(Z1)
490 E=((R(I,(Z1)))-AV(Z1))^2
500 F=F+E
510 NEXT
520 G(Z1)=(F/(MAXN(Z1)-1))^0.5
530 H(Z1)=G(Z1)/(MAXN(Z1)^0.5)
540 L(Z1)=G(Z1)*100/AV(Z1)
550 NEXT Z1
560 GOTO 580
570 END
580 I=1
590 *DRIVE 1
600 X=OPENOUT FILE$
610 PRINT #X,M
620 PRINT #X, DATE$
630 PRINT #X, NAME$
640 PRINT #X, S
650 I=1:Z1=1
```

```
660 REPEAT
670 PRINT #X,MAXN(Z1)
680 IF MAXN(Z1)=0 THEN 780
690 FOR I=1 TO MAXN(Z1)
700 PRINT #X, A(I,Z1)
710 PRINT #X, B(I,Z1)
720 PRINT #X, R(I,Z1)
730 NEXT I
740 PRINT #X, AV(I,Z1)
750 PRINT #X, G(I,Z1)
760 PRINT #X, H(I,Z1)
770 PRINT #X, L(I,Z1)
780 Z1=Z1+1:I=1
790 UNTIL Z1(6)
800 CLOSE#X
810 Z1=1:I=1
820 FOR Z1=1 TO 5
830 PRINT
840 PRINT SPC(10)"****TYPE(";Z1;")****"
850 IF MAXN(Z1)=0 THEN PRINT SPC(4)"****NO VALUE AVAILABLE ***"
    :GOTO 970
860 PRINT
870 PRINT SPC(3);"**(X1)**"SPC(4);"**(X2)**"SPC(4);"*TOTAL*"
880 FOR I=1 TO MAXN(Z1)
890 PRINT ;I;"-"SPC(3);A(I,Z1),SPC(5);B(I,Z1),SPC(8);R(I,Z1)
900 PRINT
910 NEXT I
920 PRINT "THE MEAN VALUE Xav=";AV(Z1)
930 PRINT "THE STANDARD DEVIATION IS SD=";G(Z1)
940 PRINT "THE STANDARD ERROR IS SE=";H(Z1)
950 PRINT "THE COEFFICIENT OF VARIANCE IS CV=";L(Z1);"%"
960 PRINT
970 IF Z1=5 THEN 1010
980 PRINT "PRESS ANY KEY TO PRINT NEXT TYPE"
```

```
990 Y=GET
1000 NEXT Z1
1010 *DRIVE 0
1020 @%=131850
1030 INPUT "DO YOU WANT TO PRINT THE RESULT (Y/N) ?" ANS$
1040 IF ANS$="N" THEN 1060
1050 CHAIN "OUT2"
1060 PRINT "GOOD BYE"
1070 END
```

COMPUTER PROGRAM 3

A.3 - The Average Diameter of Fibre Types from Three Birds

```
10 REM
20 REM THIS PROGRAM TO CALCULATE STATISTIC OF THREE FILES OF
   PRGRAMME.D2
30 FILES$(3), Z(3), S(3), MAXN(5,3)
40 FILE$:NAME THE THREE FILES
50 REM Z(3): NO. OF FIBRE TYPES IN EACH FILE
60 REM MAXN(5,3): MAX. NO. OF READING IN EACH FIBRE TYPE
70 REM
80 REM
90 REM *****************************************
100 INPUT "NO. OF FILE TO BE CALCULATED ?" FILENO
110 FILENO< 1 OR FILENO > 3 3 THEN VDU7: GOTO 100
120 Z=5
130 FOR I=1 TO FILENO
140 PRINT "MAME OF THE FILE (";I;") ?"
150 INPUT FILE$(I)
160 NEXT I
170 CLS
180 PRINT "PLEASE WAITE"
190 REM *****************************************
200 FLAG=0
210 FOR K=1 TO FILNO
220 PROCread
230 NEXT K
240 S=S(1)
250 FOR I=2 TO FILNO
260 IF S> S(I) THEN 280
270 S=S(I)
280 NEXT
```

```
290 DIM R(S,Z,K), AV(Z,K), H(Z,K), G(Z,K), L(Z,K)
300 REM ****************************************
310 FLAG=1
320 FOR K=1 TO FILNO
330 PROCread
340 NEXT K
350 REM ****************************************
360 PRINT "IF THE PRINTER READY PRESS ANY KEY TO CONTINUE"
370 Y=GET
380 @%=&200509
390 *FX6
400 VDU2
410 PRINT "THIS CALCULATION IS FOR THE FILES"
420 FOR I=1 TO FILNO :PRINT "FILE (";I;") IS:" ; FILE$(I):NEXT I
430 FOR Z1=I TO Z
440 PROCstat
450 PROCprint
460 NEXT Z1
470 VDU3
480 *DRIVE0
490 END
500 REM
510 REM ****************************************
520 DEF PROCread
530 *DRIVE1
540 X=OPENIN FILE$(K)
550 INPUT#X,M
560 INPUT#X,DATE$
570 INPUT#X,NAME$
580 INPUT#X,S(K)
590 IF FLAG=0 THEN 760
600 REM DIM A(S,Z), B(S,Z), R(S,Z), MAXN(Z), AV(Z), G(Z), H(Z), L(Z)
610 I=1:Z1=1
620 REPEAT
```

```
630 INPUT#X,MAXN(Z1,K)
640 IF MAXN(Z1,K)=0 YHEN 740
650 FOR I=1 TO MAXN(Z1,K)
660 INPUT#X,A
670 INPUT#X,A
680 INPUT#X,R(I,Z1,K)
690 NEXT I
700 INPUT#X,AV1
710 INPUT#X,G1
720 INPUT#X,H1
730 INPUT#X,L1
740 Z1=Z1+1:I=1
750 UNTIL EOF#X
760 CLOSE#X
770 ENDPROC
780 REM *******************************************
790 DEF PROCSTAT
800 C=0 :I=1 :MAXF=0 :AV=0 :G=0 :H=0 :L=0
810 FOR K=1 TO FILNO
820 IF MAXN(Z1,K)=0 THEN IF K>=FILNO THEN 890
830 IF MAXN(Z1,K)=0 THEN 880
840 FOR I=1 TO MAXN(Z1,K)
850 C=C+R(I,Z1,K)
860 NEXT I
870 MAXF=MAXF+MAXN(Z1,K)
880 NEXT K
890 IF MAXF=0 THEN 1030
900 AV=C/MAXF
910 F=0 :I=1
920 FOR K=1 TO FILNO
930 IF MAXN(Z1,K)=0 THEN IF K>=FILNO THEN 1000
940 IF MAXN(Z1,K)=0 THEN 990
950 FOR I=1 TO MAXN(Z1,K)
960 E=((R(I,Z1,K)-AV))^2
```

```
970 F=F+E
980 NEXT I
990 NEXT K
1000 G=(F/(MAXF-1))^0.5
1010 H=G/(MAXF)^0.5
1020 L=G*100/AV
1030 ENDPROC
1040 REM ***************************************
1050 DEF PROCprint
1060 PRINT STRING$(80,"*")
1070 IF MAXF=0 THEN PRINT SPC(20)"** NO AVAILABLE DATA FOR TYPE (";Z1;")"
    :GOTO 1130
1080 PRINT "THE NO. OF READING FOR THE =";MAXF
1090 PRINT "THE MEAN VALUE FOR TYPE (";Z1") Xav(";Z1;")=";AV
1100 PRINT "THE STANDARD DEVIATION FOR TYPE (";Z1") SD(";Z1;")=";G
1110 PRINT "THE STANDARD ERROR FOR TYPE (";Z1") SE(";Z1;")=";H
1120 PRINT "THE COEFFICIENT OF VARIANCE FOR TYPE (";Z1") CV(";Z1;")=";L;"%"
1130 ENDPROC
```

COMPUTER PROGRAM 4

A.4 - The Printing Result of the Programme D1

```
10 REM
20 REM THIS PROGRAM TO PRINT THA DATA OF PROGRAM D1
30 INPUT "THE NAME OF THE FILE TO BE PRINTED ?" FILE$
40 REM *FX6
50 VDU2
60 REM
70 REM
80 Z=5
90 *DRIVE1
100 X=OPENIN FILE$
110 INPUT#X,M
120 INPUT#X,DATE$
130 INPUT#X,NAME$
140 INPUT#X,S
150 DIM A(S,Z), B(S,Z), R(S,Z), MAXN(Z), AV(Z), G(Z), H(Z), L(Z)
160 I=1 :Z1=1
170 REPEAT
180 INPUT#X,MAXN(Z1)
190 IF MAXN(Z1)=0 THEN 290
200 FOR I=1 TO MAXN(Z1)
210 INPUT#X, A(I,Z1)
220 INPUT#X, B(I,Z1)
230 INPUT#X, R(I,Z1)
240 NEXT I
250 INPUT#X, AV(Z1)
260 INPUT#X, G(Z1)
270 INPUT#X, H(Z1)
280 INPUT#X, L(Z1)
290 Z1=Z1+1:I=1
```

```
300 UNTIL EOF#X
310 CLOSE#X
320 *DRIVE0
330 Z1=1:I=1
340 @%=&20308
350 REPEAT
360 PRINT
370 PRINT SPC(34) DATE$
380 PRINT SPC(34) STRING$(10,"-")
390 PRINT SPC(24) "DIAMETER OF FIBRE TYPES (MICRON)"
400 PRINT SPC(24) STRING$(33,"=")
410 PRINT SPC(35) NAME$
420 PRINT SPC(34) SRTING$(10,"-")
430 MAXN(Z1)=0 THEN 480
440 PRINT
450 PRINT "X1, X2 MEASURED IN (mm)"
460 PRINT "MEASURING UNIT TRANSFERED TO MICRON BY M=";M
470 PRINT
480 PRINT SPC(35) STRING$(8,"*")
490 PRINT SPC(36) "TYPE(";Z1;")"
500 PRINT SPC(35) STRING$(8,"*")
510 IF MAXN(Z1)0 THEN PRINT SPC(20)"*** NO VALUE AVAILABLE ***"
    :GOTO 650
520 PRINT
530 PRINT SPC(6);"**(X1)/mm**"SPC(13);"**(X2)/mm**"SPC(8);"** AV.
    DIAMETER/micron **"
540 I=1
550 FOR I=1 TO MAXN(Z1)
560 PRINT;I;"-"SPC(6);A(I,Z1),SPC(12); B(I,Z1), SPC(12); R(I,Z1)
570 PRINT
580 NEXT I
590 PRINT
600 PRINT "THE MEAN VALUE Xav=";AV(Z1)
610 PRINT "THE STANDARD DEVIATION IS SD=";G(Z1)
```

```
620 PRINT "THE STANDARD ERROR IS SE=";H(Z1)
630 PRINT "THE COEFFICIENT OF VARIANCE IS CV=";L(Z1);"%"
640 PRINT
650 Z1=Z1+1
660 UNTIL Z1=(Z+1)
670 VDU3
680 END
```

APPENDIX B

APPENDIX B

ANATOMICAL MEASUREMENTS ON INDIVIDUAL BIRDS

B.1 - Control Birds

Table B.1 - Measurements on the Control Birds at Age 1 Day

		Bird No. 1 Killing Wt.* 40.77		Bird No. 2 Killing Wt. 58.31		Bird No. 3 Killing Wt. 48.09		Mean Killing Wt. 49.06±8.81	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	0.21	-	0.54	-	0.40	-	0.38±0.17	-
Muscle	L	0.20	-	0.55	-	0.40	-	0.38±0.18	-
Supracoracoideus	R	0.04	-	0.10	-	0.09	-	0.08±0.03	-
Muscle	L	0.04	-	0.10	-	0.08	-	0.07±0.03	-
Clavicle	R§	0.01	10.40	0.20	13.10	0.01	10.30	0.07±0.11	11.27±1.59
Bone	L	-	10.35	-	12.35	-	10.30	-	11.00±1.17
coracoide	R	0.03	11.60	0.05	11.70	0.02	10.10	0.03±0.01	11.13±0.90
Bone	L	0.03	10.05	0.05	11.70	0.02	8.00	0.03±0.01	9.92±1.85
Posterior	R†	0.005	8.6	0.01	9.25	0.02	10.10	0.012±0.008	9.32±0.75
X. Process	L	-	8.55	-	7.35	-	10.00	-	8.63±1.33
Anterior	R	-	6.10	-	5.90	-	5.60	-	5.872±0.25
X. Process	L‡	0.005	6.05	0.01	3.90	0.02	5.50	0.012±0.008	5.15±1.12
Keel	R	-	5.60	-	5.00	-	4.40	-	5.00±0.60
Height	L	-	5.50	-	5.05	-	4.25	-	4.93±0.63
Total Sternum		0.10	16.90	0.27	19.80	0.25	20.35	0.21±0.09	19.02±1.85
# Bone Sternum		0.05	8.40	0.25	9.50	0.19	10.75	0.16±0.10	9.55±1.17
Dorsal Keel Width		-	4.30	-	4.90	-	3.65	-	4.28±0.62
Heart Wt.		0.34	-	0.49	-	0.45	-	0.43±0.08	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.2 - Measurements on the Control Birds at Age 10 Days

		Bird No. 1 Killing Wt.* 166		Bird No. 2 Killing Wt. 186		Bird No. 3 Killing Wt. 209		Mean Killing Wt. 187.00±21.52	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	6.26	-	6.90	-	8.75	-	7.32±1.31	-
Muscle	L	6.15	-	7.02	-	8.91	-	7.36±1.41	-
Supracoracoideus	R	1.53	-	1.65	-	2.10	-	1.76±0.30	-
Muscle	L	1.50	-	1.82	-	2.21	-	1.84±0.35	-
Clavicle	R§	0.06	18.90	0.09	19.80	0.10	20.80	0.08±0.02	19.83±0.95
Bone	L	-	20.60	-	20.15	-	21.35	-	20.70±0.61
Coracoid	R	0.27	20.85	0.25	21.25	0.31	22.15	0.28±0.03	21.42±0.66
Bone	L	0.29	20.80	0.26	21.80	0.32	22.00	0.29±0.03	21.53±0.64
Posterior	R†	0.06	16.45	0.04	16.75	0.10	17.40	0.07±0.03	16.87±0.48
X. Process	L	-	17.60	-	17.85	-	17.00	-	17.48±0.44
Anterior	R	-	12.45	-	11.35	-	12.35	-	12.05±0.61
X. Process	L‡	0.05	12.45	0.04	11.95	0.03	12.50	0.06±0.02	12.30±0.30
Keel	R	-	12.60	-	10.70	-	12.00	-	11.77±0.97
Height	L	-	12.05	-	10.20	-	11.90	-	11.38±1.03
Total Sternum		1.11	39.00	1.01	37.35	1.40	38.85	1.17±0.20	38.40±0.91
# Bone Sternum		0.69	12.90	0.66	14.00	0.91	15.95	0.75±0.14	14.28±1.54
Dorsal Keel Width		-	8.05	-	8.25	-	9.30	-	8.53±0.67
Heart Wt.		1.04	-	1.21	-	1.16	-	1.14±0.09	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.3 - Measurements on the Control Birds at Age 20 Days

		Bird No. 1 Killing Wt.* 374		Bird No. 2 Killing Wt. 475		Bird No. 3 Killing Wt. 466		Mean Killing Wt. 438.33±55.89	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	14.08	-	21.54	-	19.74	-	18.45±3.89	-
Muscle	L	14.26	-	21.33	-	19.73	-	18.44±3.71	-
Supracoracoideus	R	3.79	-	5.52	-	4.72	-	4.68±0.86	-
Muscle	L	3.74	-	5.87	-	4.85	-	4.82±1.06	-
Clavicle	R§	0.24	26.25	0.29	26.70	0.28	28.30	0.27±0.03	27.08±1.08
Bone	L	-	25.25	-	27.85	-	26.90	-	26.67±1.31
Coracoid	R	0.60	27.25	0.87	31.20	0.68	29.60	0.72±0.12	29.35±1.99
Bone	L	0.61	27.85	0.90	32.35	0.67	29.80	0.73±0.15	30.00±2.26
Posterior	R†	0.13	24.45	0.19	29.20	0.20	29.45	0.17±0.04	27.70±2.82
X. Process	L	-	24.05	-	29.15	-	29.65	-	27.62±3.10
Anterior	R	-	15.20	-	19.87	-	16.70	-	17.26±2.38
X. Process	L‡	0.13	15.65	0.19	19.90	0.16	16.70	0.16±0.03	17.42±2.21
Keel	R	-	15.90	-	19.20	-	16.20	-	17.10±1.82
Height	L	-	15.55	-	19.50	-	15.95	-	16.98±2.19
Total Sternum		2.87	49.75	3.84	55.95	3.46	54.50	3.39±0.49	53.40±3.24
# Bone Sternum		2.02	9.70	2.72	14.25	2.34	12.85	2.36±0.35	12.27±2.33
Dorsal Keel Width		-	11.90	-	12.25	-	11.55	-	11.90±0.35
Heart Wt.		2.88	-	3.20	-	3.00	-	3.03±0.16	

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.4 - Measurements on the Control Birds at Age 30 Days

		Bird No. 1 Killing Wt.* 875		Bird No. 2 Killing Wt. 920		Bird No. 3 Killing Wt. 1045		Mean Killing Wt. 946.67±88.08	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	43.96	-	45.65	-	47.71	-	45.77±1.88	-
Muscle	L	46.20	-	46.32	-	47.32	-	46.61±0.61	-
Supracoracoideus	R	13.41	-	12.61	-	13.18	-	13.07±0.41	-
Muscle	L	13.68	-	12.55	-	12.81	-	13.01±0.59	-
Clavicle	R§	0.61	34.15	0.66	34.25	0.73	35.65	0.67±0.06	34.68±0.84
Bone	L	-	34.45	-	34.10	-	34.85	-	34.47±0.37
Coracoid	R	1.56	37.05	1.81	40.10	1.97	42.15	1.78±0.21	39.77±2.57
Bone	L	1.54	38.75	1.86	40.00	1.92	41.25	1.77±0.20	40.00±1.25
Posterior	R†	0.34	36.90	0.60	41.80	0.52	39.70	0.49±0.13	39.47±2.46
X. Process	L	-	38.75	-	39.00	-	36.35	-	38.03±1.46
Anterior	R	-	22.55	-	25.35	-	24.75	-	25.27±2.57
X. Process	L‡	0.30	22.75	0.57	25.35	0.42	24.75	0.43±0.13	24.28±1.36
Keel	R	-	22.85	-	24.20	-	23.35	-	23.47±0.68
Height	L	-	22.85	-	24.30	-	23.25	-	23.47±0.75
Total Sternum		5.90	66.70	7.18	76.55	7.34	74.60	6.81±0.79	72.62±5.21
# Bone Sternum		4.42	15.85	5.29	20.40	5.28	20.55	5.00±0.50	18.93±2.67
Dorsal Keel Width		-	12.75	-	13.85	-	14.10	-	13.57±0.72
Heart Wt.		6.57	-	5.74	-	7.75	-	6.69±1.01	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.5 - Measurements on the Control Birds at Age 40 Days

		Bird No. 1 Killing Wt.* 1495		Bird No. 2 Killing Wt. 1587		Bird No. 3 Killing Wt. 1780		Mean Killing Wt. 1620.67±145.45	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	64.95	-	79.94	-	86.17	-	77.02±10.91	-
Muscle	L	66.32	-	87.83	-	88.64	-	80.93±12.66	-
Supracoracoideus	R	18.34	-	21.49	-	23.68	-	21.17±2.68	-
Muscle	L	19.00	-	23.37	-	24.14	-	22.17±2.77	-
Clavicle	R§	0.70	43.90	0.90	46.85	0.86	47.00	0.82±0.10	45.92±1.75
Bone	L	-	45.25	-	47.10	-	47.10	-	46.48±1.07
Coracoid	R	2.73	47.35	2.56	46.85	2.80	48.30	2.70±0.12	47.50±0.74
Bone	L	2.64	47.15	2.51	46.65	2.67	46.85	2.61±0.08	46.88±0.25
Posterior	R†	0.54	46.20	0.57	42.35	0.63	49.75	0.58±0.04	46.10±3.70
X. Process	L	-	46.35	-	41.90	-	45.00	-	44.42±2.28
Anterior	R	-	27.90	-	27.18	-	27.05	-	27.38±0.46
X. Process	L‡	0.52	27.50	0.65	26.90	0.64	26.50	0.60±0.07	26.97±0.50
Keel	R	-	24.55	-	28.90	-	28.85	-	27.43±2.50
Height	L	-	24.55	-	27.80	-	27.95	-	26.77±0.75
Total Sternum		9.32	84.65	11.21	86.20	11.50	93.15	10.68±1.18	88.00±4.53
# Bone Sternum		6.87	23.60	8.07	28.90	8.92	28.25	7.95±1.03	26.92±2.89
Dorsal Keel Width		-	17.45	-	17.05	-	17.20	-	17.23±0.20
Heart Wt.		8.45	-	10.69	-	9.62	-	9.59±1.12	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.6 - Measurements on the Control Birds at Age 50 Days

		Bird No. 1 Killing Wt.* 2065		Bird No. 2 Killing Wt. 2398		Bird No. 3 Killing Wt. 2627		Mean Killing Wt. 2363.33±282.60	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	115.17	-	139.10	-	149.64	-	134.64±17.66	-
Muscle	L	120.94	-	141.45	-	154.88	-	139.09±17.09	-
Supracoracoideus	R	32.52	-	37.28	-	38.77	-	36.19±3.26	-
Muscle	L	33.78	-	36.80	-	40.45	-	37.99±3.34	-
Clavicle	R§	0.96	51.05	1.23	52.55	1.82	56.25	1.34±0.44	53.28±2.68
Bone	L	-	51.05	-	53.25	-	56.95	-	53.75±2.98
Coracoid	R	2.92	52.70	3.61	52.50	4.86	58.45	3.80±0.98	54.55±3.38
Bone	L	3.03	54.00	4.07	54.40	5.03	57.40	4.04±1.00	55.27±1.86
Posterior	R†	0.82	52.75	0.99	57.25	1.24	58.25	1.02±0.21	56.07±2.92
X. Process	L	-	53.00	-	58.10	-	58.90	-	56.67±3.20
Anterior	R	-	31.75	-	32.45	-	33.75	-	32.55±1.15
X. Process	L‡	0.77	31.75	0.84	32.40	1.14	37.45	0.92±0.20	33.87±3.12
Keel	R	-	27.90	-	30.05	-	33.65	-	30.53±2.90
Height	L	-	29.35	-	30.70	-	34.00	-	31.35±2.43
Total Sternum		13.22	101.05	16.39	105.60	19.75	107.25	16.45±3.26	104.63±3.21
# Bone Sternum		9.34	31.35	12.16	36.55	14.25	37.10	11.92±2.46	35.00±3.17
Dorsal Keel Width		-	20.10	-	18.20	-	21.05	-	19.78±1.45
Heart Wt.		13.60	-	15.18	-	15.41	-	14.73±0.98	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.7 - Measurements on the Control Birds at Age 60 Days

		Bird No. 1 Killing Wt.* 3037		Bird No. 2 Killing Wt. 3355		Bird No. 3 Killing Wt. 3470		Mean Killing Wt. 3287.33±224.29	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	174.28	-	242.04	-	214.39	-	210.24±34.07	-
Muscle	L	174.34	-	251.12	-	224.42	-	216.63±38.98	-
Supracoracoideus	R	53.31	-	60.75	-	56.10	-	56.72±3.76	-
Muscle	L	52.16	-	63.07	-	56.96	-	57.40±5.47	-
Clavicle	R§	1.62	52.45	1.89	54.75	2.04	55.00	1.85±0.21	54.07±1.40
Bone	L	-	54.30	-	55.00	-	54.25	-	54.52±0.42
Coracoid	R	4.69	61.35	5.09	60.05	5.34	58.70	5.04±0.33	60.03±1.32
Bone	L	4.78	60.15	5.09	61.20	5.95	59.85	5.27±0.61	60.40±0.71
Posterior	R†	1.18	60.40	1.36	62.80	1.54	62.05	1.36±0.18	61.75±1.23
X. Process	L	-	58.25	-	59.35	-	63.40	-	60.33±2.71
Anterior	R	-	37.10	-	38.15	-	36.50	-	37.25±0.83
X. Process	L‡	1.24	38.70	1.49	37.25	1.69	34.70	1.47±0.22	36.88±2.02
Keel	R	-	32.95	-	34.65	-	34.30	-	33.97±0.90
Height	L	-	31.90	-	34.35	-	34.95	-	33.73±1.62
Total Sternum		20.84	111.25	22.55	110.70	23.63	114.25	22.34±1.41	112.07±1.91
# Bone Sternum		15.37	42.50	16.23	37.35	18.06	46.20	16.55±1.37	42.02±4.44
Dorsal Keel Width		-	22.70	-	20.30	-	23.75	-	22.25±1.77
Heart Wt.		16.98	-	17.34	-	17.51	-	17.28±0.27	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.8 - Measurements on the Control Birds at Age 70 Days

		Bird No. 1 Killing Wt.* 3570		Bird No. 2 Killing Wt. 3850		Bird No. 3 Killing Wt. 4150		Mean Killing Wt. 3856.67±290.06	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	245.67	-	304.09	-	296.04	-	281.93±31.66	-
Muscle	L	255.04	-	326.46	-	307.89	-	296.46±37.05	-
Supracoracoideus	R	69.50	-	77.41	-	72.72	-	73.21±3.98	-
Muscle	L	69.62	-	72.26	-	70.97	-	70.95±1.32	-
Clavicle	R§	1.66	56.40	1.46	56.30	2.29	57.40	1.80±0.43	56.70±0.61
Bone	L	-	55.05	-	56.90	-	56.65	-	56.20±1.00
Coracoid	R	5.01	60.00	3.95	55.50	8.00	64.75	5.65±2.10	60.08±4.62
Bone	L	4.99	60.40	3.94	54.95	6.84	64.10	5.26±1.47	59.82±4.60
Posterior	R†	1.34	55.20	1.33	62.10	1.72	69.40	1.46±0.22	62.23±7.10
X. Process	L	-	56.75	-	64.95	-	65.75	-	62.48±4.98
Anterior	R†	-	35.50	-	39.05	-	39.00	-	37.85±2.03
X. Process	L‡	1.07	35.70	1.31	41.05	1.80	37.85	1.39±0.37	38.20±2.69
Keel	R	-	35.80	-	36.50	-	36.95	-	36.42±0.58
Height	L	-	36.80	-	36.45	-	36.40	-	36.48±0.40
Total Sternum		20.15	117.35	18.38	113.75	27.86	124.20	22.13±5.04	118.43±5.31
# Bone Sternum		15.89	56.90	12.73	43.10	21.07	41.85	16.56±4.21	47.28±8.35
Dorsal Keel Width		-	21.45	-	22.80	-	25.40	-	23.22±2.01
Heart Wt.		18.24	-	19.71	-	20.83	-	19.59±1.30	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.9 - Measurements on the Control Birds at Age 100 Days

		Bird No. 1 Killing Wt.* 4380		Bird No. 2 Killing Wt. 4500		Bird No. 3 Killing Wt. 4800		Mean Killing Wt. 4560.00±216.33	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis Muscle	R	317.30	-	386..96	-	378.85	-	361.04±38.09	-
	L	316.27	-	393.12	-	392.11	-	367.17±44.08	-
Supracoracoideus Muscle	R	86.53	-	88.65	-	84.94	-	86.71±1.86	-
	L	87.91	-	89.67	-	85.87	-	87.82±1.90	-
Clavicle Bone	R§	2.95	59.90	3.52	70.35	3.05	68.10	3.17±0.30	66.12±5.50
	L	-	61.40	-	69.25	-	66.50	-	65.72±3.98
Coracoid Bone	R	4.85	61.35	10.40	70.90	7.15	68.90	7.47±2.79	67.05±5.04
	L	5.17	59.80	10.11	69.75	6.98	68.30	7.42±2.50	65.95±5.38
Posterior X. Process	R†	1.62	75.20	2.28	73.00	2.17	77.65	2.02±0.35	75.28±2.33
	L	-	69.50	-	70.45	-	77.55	-	72.50±4.40
Anterior X. Process	R	-	43.75	-	46.05	-	45.30	-	45.03±1.17
	L‡	1.63	44.20	2.20	41.40	1.77	42.70	1.87±0.30	42.77±1.40
Keel Height	R	-	39.85	-	41.80	-	41.80	-	41.15±1.12
	L	-	39.65	-	46.50	-	43.00	-	43.05±3.42
Total Sternum		16.55	130.60	37.48	152.00	24.67	146.25	26.23±10.55	142.95±11.08
# Bone Sternum		15.35	68.65	30.74	79.15	19.66	79.75	21.92±7.94	75.85±6.24
Dorsal Keel Width		-	22.25	-	27.70	-	31.05	-	27.00±4.44
Heart Wt.		18.93	-	29.98	-	23.88	-	24.26±5.53	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

\# Bone weight only after removing the cartilage

Table B.10 - Measurements on the Control Birds at Age 150 Days

		Bird No. 1 Killing Wt.* 6940		Bird No. 2 Killing Wt. 6020		Mean Killing Wt. 6480.00±650.54	
		Weight*	Length**	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	454.54	-	474.42	-	464.48±14.06	-
Muscle	L	476.40	-	513.17	-	494.78±26.00	-
Supracoracoideus	R	136.40	-	132.41	-	134.40±2.82	-
Muscle	L	135.57	-	133.57	-	134.57±1.41	-
Clavicle	R§	2.69	61.85	3.40	66.45	3.04±0.50	64.15±3.25
Bone	L	-	66.05	-	67.30	-	66.67±0.88
Coracoid	R	8.02	68.90	9.14	74.55	8.58±0.79	71.72±3.99
Bone	L	7.70	68.95	9.30	74.10	8.50±1.13	71.52±3.64
Posterior	R†	2.40	93.30	3.18	97.80	2.79±0.55	95.55±3.18
X. Process	L	-	88.30	-	94.15	-	91.22±4.14
Anterior	R	-	55.15	-	56.60	-	55.87±1.02
X. Process	L‡	2.66	52.85	2.83	52.35	2.74±0.12	52.60±0.35
Keel	R	-	48.10	-	48.75	-	48.42±0.46
Height	L	-	49.00	-	50.00	-	49.50±0.71
Total Sternum		22.68	150.09	28.47	165.70	25.57±4.09	157.89 ±11.04
# Bone Sternum		22.26	137.00	27.34	149.00	24.80±3.59	143.00 ±8.48
Dorsal Keel Width		-	29.65	-	28.75	-	29.20±0.64
Heart Wt.		26.82	-	35.88	-	31.35±6.41	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

B.2 - Selected Chickens

Table B.11 - Measurements on the Selected Birds at Age 20 Days

		Bird No. 1 Killing Wt.* 377.9		Bird No. 2 Killing Wt. 453.5		Bird No. 3 Killing Wt. 471.5		Mean Killing Wt. 403.1±43.65	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	13.52	-	20.22	-	19.31	-	17.68±3.63	-
Muscle	L	13.83	-	21.96	-	20.40	-	18.73±4.31	-
Supracoracoideus	R	3.72	-	5.72	-	4.70	-	4.71±1.00	-
Muscle	L	3.82	-	5.74	-	4.99	-	4.85±0.97	-
Clavicle	R§	0.20	26.15	0.33	26.70	0.34	26.00	0.29±0.05	26.28±0.37
Bone	L	-	25.25	-	27.10	-	27.45	-	26.60±1.18
Coracoid	R	1.10	31.60	1.18	35.95	1.04	32.80	1.11±0.07	33.45±2.25
Bone	L	0.83	26.40	1.12	34.70	1.04	31.85	1.00±0.15	30.98±4.22
Posterior	R†	0.19	30.20	0.23	32.00	0.25	31.00	0.22±0.03	31.27±0.64
X. Process	L	-	28.90	-	34.30	-	31.10	-	31.43±2.71
Anterior	R	-	17.45	-	18.6	-	19.5	-	18.52±1.03
X. Process	L‡	0.14	15.40	0.27	17.60	0.22	19.30	0.21±0.06	17.43±1.95
Keel	R	-	15.25	-	19.05	-	17.00	-	17.10±1.90
Height	L	-	14.85	-	19.35	-	17.30	-	17.17±2.25
Total Sternum		2.73	50.70	3.88	62.80	3.70	59.50	3.44±0.62	57.67±6.25
# Bone Sternum		1.95	11.25	2.85	11.70	2.75	12.15	2.52±0.49	11.7±0.45
Dorsal Keel Width		-	9.35	-	14.15	-	11.40	-	11.63±2.41
Heart Wt.		2.66	-	2.87	-	3.08	-	2.87±0.21	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.12 - Measurements on the Selected Birds at Age 30 Days

		Bird No. 1 Killing Wt.* 906		Bird No. 2 Killing Wt. 1010		Mean Killing Wt. 958.00±73.54	
		Weight*	Length**	Weight	Length	Weight±SD	Length±SD
Pectoralis Muscle	R	38.54	-	41.72	-	40.13±2.25	-
	L	39.90	-	45.33	-	42.61±3.84	-
Supracoracoideus Muscle	R	13.25	-	12.34	-	12.79±0.64	-
	L	13.92	-	12.92	-	13.42±0.71	-
Clavicle Bone	R§	0.47	33.30	0.56	34.00	0.51±0.06	33.65±0.49
	L	-	33.80	-	33.70	-	33.75±0.07
Coracoid Bone	R	1.38	37.65	1.90	41.65	1.64±0.37	39.65±2.83
	L	1.46	38.75	2.07	42.45	1.76±0.43	40.60±2.62
Posterior X. Process	R†	0.32	36.40	0.45	36.95	0.39±0.09	36.67±0.39
	L	-	37.65	-	36.15	-	36.90±1.06
Anterior X. Process	R	-	22.20	-	20.55	-	21.37±1.17
	L‡	0.35	21.85	0.37	21.35	0.36±0.01	21.60±0.35
Keel Height	R	-	21.85	-	21.05	-	21.45±0.56
	L	-	21.85	-	20.90	-	21.37±0.67
Total Sternum		6.62	70.50	6.75	69.65	6.68±0.09	70.07 ±0.60
# Bone Sternum		4.77	18.20	4.99	21.00	4.88±0.15	19.60 ±1.98
Dorsal Keel Width		-	14.75	-	14.30	-	14.52±0.32
Heart Wt.		6.40	-	8.33	-	7.36±1.36	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

\# Bone weight only after removing the cartilage

Table B.13 - Measurements on the Selected Birds at Age 40 Days

		Bird No. 1 Killing Wt.* 1272		Bird No. 2 Killing Wt. 1292		Bird No. 3 Killing Wt. 11679		Mean Killing Wt. 1414.33±229.43	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	65.98	-	53.98	-	95.50	-	71.82±21.37	-
Muscle	L	67.72	-	56.33	-	108.50	-	77.52±27.43	-
Supracoracoideus	R	17.52	-	16.31	-	23.67	-	19.17±3.95	-
Muscle	L	17.51	-	16.56	-	23.79	-	19.29±3.93	-
Clavicle	R§	0.89	36.15	0.73	35.75	1.02	38.30	0.88±0.14	36.73±1.37
Bone	L	-	35.95	-	36.10	-	38.55	-	36.87±1.46
Coracoid	R	2.04	42.60	1.98	43.35	2.51	45.95	2.18±0.29	43.97±1.76
Bone	L	2.15	42.25	1.94	42.95	2.85	47.35	2.31±0.48	44.18±2.76
Posterior	R†	0.56	39.55	0.46	41.10	0.64	45.80	0.55±0.09	42.15±3.25
X. Process	L	-	39.75	-	41.30	-	46.35	-	42.47±3.45
Anterior	R	-	21.05	-	22.28	-	27.00	-	23.42±3.16
X. Process	L‡	0.51	23.40	0.41	23.40	0.74	27.95	0.55±0.17	24.92±2.63
Keel	R	-	25.45	-	24.85	-	26.10	-	25.47±0.62
Height	L	-	23.75	-	23.55	-	25.25	-	24.18±0.93
Total Sternum		8.52	78.00	8.20	76.55	9.84	78.15	8.85±0.87	77.57±0.88
# Bone Sternum		6.40	22.65	6.17	24.10	8.12	29.85	6.90±1.06	25.53±3.81
Dorsal Keel Width		-	15.70	-	15.30	-	16.95	-	15.98±0.86
Heart Wt.		10.52	-	7.97	-	10.57	-	9.69±0.25	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

\# Bone weight only after removing the cartilage

Table B.14 - Measurements on the Selected Birds at Age 50 Days

		Bird No. 1 Killing Wt.* 2433		Bird No. 2 Killing Wt. 2555		Bird No. 3 Killing Wt. 2920		Mean Killing Wt. 2636.00±253.40	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	133.50	-	153.02	-	161.03	-	149.18±14.16	-
Muscle	L	145.22	-	160.38	-	168.58	-	158.06±11.85	-
Supracoracoideus	R	33.55	-	40.03	-	40.70	-	38.09±3.95	-
Muscle	L	34.99	-	39.26	-	41.90	-	38.72±3.49	-
Clavicle	R§	1.69	43.95	1.51	41.90	1.31	44.60	1.50±0.19	43.48±1.41
Bone	L	-	45.10	-	42.60	-	45.45	-	44.38±1.55
Coracoid	R	3.33	49.62	3.96	53.30	3.70	53.20	3.66±0.32	52.04±2.10
Bone	L	3.53	50.00	4.14	52.50	4.00	53.05	3.89±0.32	51.85±1.62
Posterior	R†	1.18	52.20	0.90	49.00	1.03	53.15	1.04±0.14	51.45±2.17
X. Process	L	-	52.25	-	47.00	-	53.55	-	50.93±3.47
Anterior	R	-	29.75	-	29.70	-	33.85	-	31.10±2.38
X. Process	L‡	1.01	31.20	1.00	29.10	1.10	33.35	1.04±0.05	31.22±2.12
Keel	R	-	29.90	-	29.55	-	32.90	-	30.78±1.84
Height	L	-	30.25	-	30.65	-	33.95	-	31.62±2.03
Total Sternum		16.32	102.55	18.30	103.20	16.88	102.60	17.17±1.02	102.78±0.36
# Bone Sternum		13.89	38.00	13.88	31.15	12.64	34.35	13.47±0.72	34.50±3.43
Dorsal Keel Width		-	20.55	-	21.35	-	22.55	-	21.48±1.01
Heart Wt.		15.77	-	15.22	-	15.70	-	15.56±0.30	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage.

Table B.15 - Measurements on the Selected Birds at Age 60 Days

		Bird No. 1 Killing Wt.* 3065		Bird No. 2 Killing Wt. 3445		Bird No. 3 Killing Wt. 3570		Mean Killing Wt. 3360.00±263.01	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	205.10	-	201.15	-	228.83	-	211.69±14.97	-
Muscle	L	210.45	-	215.17	-	235.35	-	220.32±13.22	-
Supracoracoideus	R	53.74	-	56.26	-	60.85	-	56.95±3.60	-
Muscle	L	53.52	-	55.98	-	59.93	-	56.48±3.23	-
Clavicle	R§	2.32	49.90	2.11	50.45	1.91	46.20	2.11±0.20	48.85±2.31
Bone	L	-	48.95	-	52.25	-	51.15	-	50.78±1.68
Coracoid	R	6.17	60.25	5.48	61.45	4.97	61.75	5.54±0.60	61.15±0.79
Bone	L	5.95	58.45	5.36	60.00	5.56	61.55	5.62±0.30	60.00±1.55
Posterior	R†	1.28	64.35	1.50	59.95	2.00	66.25	1.59±0.37	63.52±3.23
X. Process	L	-	62.65	-	59.25	-	66.65	-	62.85±3.70
Anterior	R	-	35.35	-	36.95	-	40.95	-	37.75±2.88
X. Process	L‡	1.65	36.05	1.32	36.10	1.79	38.85	1.59±0.24	37.00±1.60
Keel	R	-	37.20	-	34.10	-	36.40	-	35.90±1.61
Height	L	-	37.70	-	33.75	-	36.35	-	35.93±2.01
Total Sternum		25.66	116.35	26.86	112.45	21.40	112.55	24.64±2.87	113.78±2.22
# Bone Sternum		19.37	45.75	19.43	44.15	15.81	43.55	18.20±2.07	44.48±1.14
Dorsal Keel Width		-	24.90	-	23.45	-	23.40	-	23.92±0.85
Heart Wt.		16.69	-	20.62	-	20.14	-	19.15±2.14	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.16 - Measurements on the Selected Birds at Age 70 Days

		Bird No. 1 Killing Wt.* 4060		Bird No. 2 Killing Wt. 4200		Bird No. 3 Killing Wt. 4500		Mean Killing Wt. 4253.33±224.80	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	256.58	-	249.82	-	309.00	-	271.80±32.39	-
Muscle	L	261.76	-	262.14	-	313.60	-	279.17±29.82	-
Supracoracoideus	R	75.92	-	72.95	-	82.35	-	77.07±4.80	-
Muscle	L	75.73	-	75.48	-	81.88	-	77.70±3.62	-
Clavicle	R§	2.37	56.90	2.38	55.55	2.51	54.70	2.42±0.08	55.72±1.11
Bone	L	-	55.75	-	54.15	-	56.00	-	53.00±1.00
Coracoid	R	6.09	66.45	6.92	65.50	6.83	69.60	6.61±0.45	67.18±2.15
Bone	L	6.61	66.20	6.35	64.95	6.74	69.75	6.57±0.20	66.97±2.49
Posterior	R†	2.08	68.50	1.89	71.25	2.46	66.00	2.14±0.29	68.58±2.62
X. Process	L	-	66.40	-	68.45	-	65.90	-	66.92±1.35
Anterior	R†	-	42.75	-	45.40	-	42.35	-	43.50±1.66
X. Process	L‡	1.66	40.70	1.60	43.20	2.35	40.65	1.87±0.42	41.52±1.46
Keel	R	-	38.75	-	38.92	-	40.60	-	39.42±1.02
Height	L	-	38.85	-	39.88	-	41.55	-	40.09±1.36
Total Sternum		25.92	121.05	24.96	122.40	28.49	127.70	26.46±1.82	123.72±3.51
# Bone Sternum		20.21	58.75	20.05	63.10	22.71	61.52	20.99±1.49	61.12±2.20
Dorsal Keel Width		-	29.25	-	29.65	-	25.00	-	27.97±2.58
Heart Wt.		19.71	-	21.20	-	23.50	-	21.80±1.93	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.17 - Measurements on the Selected Birds at Age 100 Days

		Bird No. 1 Killing Wt.* 5500		Bird No. 2 Killing Wt. 5600		Bird No. 3 Killing Wt. 6250		Mean Killing Wt. 5783.33±407.23	
		Weight*	Length**	Weight	Length	Weight	Length	Weight±SD	Length±SD
Pectoralis	R	333.96	-	394.60	-	393.80	-	374.12±34.78	-
Muscle	L	378.87	-	409.58	-	425.46	-	404.64±23.68	-
Supracoracoideus	R	100.76	-	117.60	-	108.74	-	109.03±8.42	-
Muscle	L	98.00	-	117.20	-	111.57	-	108.92±9.87	-
Clavicle	R§	3.74	58.90	2.93	55.55	3.25	60.25	3.31±0.41	58.23±2.42
Bone	L	-	58.65	-	57.05	-	60.95	-	58.88±1.96
Coracoid	R	9.71	72.25	10.15	71.90	10.04	73.35	9.97±0.23	72.50±0.76
Bone	L	9.22	72.20	10.00	71.80	10.22	71.25	9.81±0.52	71.75±0.48
Posterior	R†	3.94	84.30	4.40	88.90	3.49	83.70	3.94±0.45	85.63±2.84
X. Process	L	-	82.95	-	80.75	-	83.30	-	82.33±1.38
Anterior	R	-	52.25	-	55.80	-	50.75	-	53.03±2.56
X. Process	L‡	3.82	52.95	3.36	50.35	4.53	52.40	3.90±0.59	51.90±1.37
Keel	R	-	40.85	-	37.95	-	45.50	-	41.43±3.81
Height	L	-	41.85	-	42.45	-	46.75	-	43.68±2.67
Total Sternum		25.36	137.30	31.58	149.35	33.29	151.90	30.08±4.17	146.18±7.80
# Bone Sternum		20.17	70.65	25.95	77.10	26.80	78.40	24.31±3.61	75.38±4.15
Dorsal Keel Width		-	28.65	-	25.15	-	26.70	-	26.83±1.75
Heart Wt.		28.77	-	27.33	-	29.36	-	28.49±1.04	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

Table B.18 - Measurements on the Selected Birds at Age 150 Days

		Bird No. 1 Killing Wt.* 7150 Weight*	 Length**
Pectoralis	R	492.22	-
Muscle	L	521.25	-
Supracoracoideus	R	137.96	-
Muscle	L	137.22	-
Clavicle	R§	2.43	56.30
Bone	L	-	55.75
Coracoid	R	7.71	69.35
Bone	L	8.10	68.40
Posterior	R†	2.54	88.25
X. Process	L	-	83.45
Anterior	R	-	50.47
X. Process	L‡	2.42	50.20
Keel	R	-	47.75
Height	L	-	46.45
Total Sternum		27.27	155.00
# Bone Sternum		26.00	139.35
Dorsal Keel Width		-	29.80
Heart Wt.		34.40	-

* Weight in grams.

** Length in millimeter

§ Weights as the total of the right and left side.

† Weights as the right posterior and anterior x. process

‡ Weights as the left posterior and anterior x. process

Bone weight only after removing the cartilage

APPENDIX C

APPENDIX C

HISTOCHEMICAL RESULT OF THE FIBRE TYPES NUMBER AND DIAMETER IN THE PECTORALIS MUSCLE

C.1 - Control Chickens

Table C.1 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 20 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	62.76±15.86†	62.05±11.25	1084.20±50.10	1209.00±56.21	19.69±0.56	21.04±0.75	23.10±0.71
		14.08	B	6.74±4.61	87.94±33.33	1122.30±45.74	1217.00±7.80	18.42±1.22	19.25±0.85	23.71±0.67
1	374.00	L	A	15.60±15.60	69.26±51.02	1117.40±140.60	1202.30±92.62	16.86±0.61	19.83±0.61	25.23±0.58
		14.26	B	14.89±7.09	32.27±2.48	1493.20±74.11	1540.40±83.68	12.60±0.54	16.82±0.67	21.10±0.71
		R	A	27.86±7.50	74.06±7.14	815.26±26.78	917.18±20.56	20.71±0.63	25.42±0.66	29.32±0.99
		19.74	B	1.06±0.35	60.28±17.73	1117.00±48.93	1178.30±30.85	17.35±1.89	20.10±0.65	24.51±0.63
2	466.00	L	A	34.04±17.24	71.06±30.62	804.36±108.63	909.46±73.13	18.89±0.40	22.49±0.74	28.88±0.59
		19.73	B	12.76±4.25	80.49±32.05	924.78±39.00	1018.00±11.70	18.76±0.55	23.34±0.89	26.75±0.60
		R	A	21.28±6.26	92.48±18.75	737.70±58.28	851.45±35.46	23.11±1.03	27.47±1.18	32.78±0.62
		21.54	B	38.06±12.62	82.74±25.78	949.36±53.74	1070.20±40.89	17.21±1.30	23.61±1.15	29.12±0.58
3	475.00	L	A	36.03±19.00	88.22±23.72	839.53±22.33	963.78±24.81	23.59±0.51	26.08±1.15	27.45±0.99
		21.54	B	38.06±12.62	96.80±28.72	880.45±33.69	1015.90±55.67	16.55±0.52	20.83±0.75	27.53±0.97
		R	A	34.53±6.63	76.81±7.31	858.25±41.73	969.59±40.78	20.83±0.43	24.80±0.66	28.68±0.66
		18.45±2.25	B	18.54±8.49	77.81±13.57	1046.70±42.54	1143.00±31.40	17.53±0.90	21.30±0.63	26.32±0.45
Mean	438.33±32.27	L	A	31.09±10.34	77.25±17.28	890.14±60.40	998.48±46.77	19.92±0.43	22.71±0.59	31.15±0.72
		18.44±2.14	B	22.10±5.93	69.85±15.52	1099.50±126.93	1191.40±113.39	16.97±0.43	20.92±0.59	25.38±0.54

† Mean± SE

Table C.2 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 30 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	15.60±9.97†	43.70±11.13	538.10±29.89	597.40±16.08	33.00±0.90	39.37±1.54	43.55±1.30
		43.96	B	31.91±11.53	39.95±6.25	492.65±21.70	564.51±15.84	24.59±0.43	28.28±1.19	37.52±0.81
1	875.00	L	A	6.38±5.33	24.35±13.81	556.47±39.66	587.21±22.55	25.65±0.76	32.42±0.78	39.52±0.93
		46.20	B	18.20±10.25	10.16±1.32	666.87±31.92	695.24±26.80	20.29±0.58	25.73±1.26	34.75±1.03
		R	A	23.81±7.90	48.83±13.13	544.76±24.41	617.40±31.66	27.97±0.83	30.06±0.73	37.44±1.19
		45.65	B	16.31±13.87	42.55±1.08	603.28±34.29	662.14±19.76	22.72±0.65	26.58±1.10	36.77±0.94
2	920.00	L	A	21.58±11.07	38.09±6.74	607.87±24.55	667.55±12.10	24.30±0.48	30.63±0.96	38.68±1.06
		46.32	B	7.62±3.67	54.25±6.97	577.99±21.43	639.86±19.14	21.68±0.78	25.61±0.65	39.51±0.92
		R	A	11.79±7.97	60.46±6.08	448.56±25.73	520.81±15.93	34.74±0.72	45.00±0.95	48.40±1.16
		47.71	B	5.32±3.28	13.83±9.94	659.01±44.01	678.16±35.43	29.46±1.07	31.47±0.94	32.22±0.72
3	1045.00	L	A	5.23±2.60	51.86±6.64	493.33±14.89	550.42±12.51	31.43±1.02	36.12±1.08	41.26±0.91
		47.32	B	-	1.89±0.68	711.08±6.10	713.09±6.00	-	24.32±1.98	28.59±0.76
		R	A	16.77±4.93	51.09±5.87	508.98±17.62	576.85±12.15	31.67±0.56	38.03±0.92	42.84±0.82
		45.77±1.08	B	16.59±6.05	30.28±6.00	591.67±30.39	638.55±22.27	25.06±0.47	28.94±0.67	35.65±0.53
Mean	946.67±50.85	L	A	11.01±4.24	39.41±5.50	549.97±17.88	599.97±14.04	26.51±0.51	33.03±0.58	39.82±0.56
		46.61±0.35	B	6.540±3.06	19.91±6.96	659.93±18.85	686.38±12.12	21.02±0.50	25.40±0.58	35.03±0.70

† Mean± SE

Table C.3 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 40 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	20.56±8.82†	49.92±17.48	446.16±60.37	516.03±35.03	38.40±0.78	46.90±0.90	45.98±1.16
		64.95	B	-	44.10±13.86	603.15±28.25	647.40±17.52	-	30.23±1.36	36.81±0.95
1	1495.00	L	A	3.37±1.84	55.54±20.33	448.50±42.21	507.71±24.50	32.31±1.83	41.05±1.27	41.23±1.02
		66.32	B	-	23.64±10.33	625.89±8.80	649.53±8.28	-	37.28±2.66	38.04±1.13
		R	A	8.98±3.02	14.89±6.14	420.02±21.41	444.60±13.00	36.34±1.06	34.71±1.37	45.81±2.71
		79.94	B	12.71±6.62	11.34±3.25	545.29±7.58	560.89±3.95	27.77±1.47	39.71±2.30	39.12±1.46
2	1587.00	L	A‡	-	-	-	-	-	-	-
		87.83	B	2.36±1.25	19.38±7.00	401.58±26.04	423.33±18.14	33.62±5.38	45.96±2.44	44.98±1.68
		R	A	6.03±2.69	28.19±11.01	363.94±24.08	398.15±19.56	35.35±1.06	45.39±1.89	49.49±1.65
		86.17	B	1.06±0.61	16.31±4.59	366.24±21.73	383.62±21.44	22.82±2.24	36.30±1.80	53.00±2.00
3	1780.00	L	A	20.74±6.38	24.82±8.67	344.62±4.14	390.18±11.37	33.27±1.45	41.48±1.71	49.36±1.63
		88.64	B	-	14.42±8.13	393.78±10.96	408.20±13.71	-	36.80±2.54	49.03±1.82
		R	A	12.82±4.10	33.92±8.83	367.54±27.23	476.68±20.74	36.82±0.58	43.54±1.03	47.16±1.02
		77.02±6.30	B	2.30±1.64	26.65±7.18	509.72±33.91	537.84±35.73	27.08±1.35	33.63±1.11	41.31±1.01
Mean	1620.67±83.98	L	A	12.05±4.50	40.32±11.79	396.56±27.76	448.94±25.49	33.06±0.88	41.50±0.92	46.13±0.92
		80.93±7.31	B	0.790±0.53	19.14±3.78	473.75±39.00	493.69±78.04	33.62±5.38	40.65±1.62	43.96±1.03

† Mean± SE

‡ The frozen tissue has been lost

Table C.4 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 50 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	3.97±1.28†	10.92±3.86	262.65±15.57	277.54±13.78	26.45±4.06	50.89±2.61	57.87±1.86
		115.17	B	0.95±0.62	2.36±0.24	337.57±13.54	340.88±14.16	29.53±3.23	35.00±2.97	51.56±1.54
1	2065.00	L	A	7.62±2.80	18.44±3.29	289.31±13.88	315.37±11.54	34.75±2.40	53.84±1.84	55.76±1.63
		120.94	B	7.09±1.88	16.54±4.14	371.33±13.43	394.96±14.48	29.08±1.42	31.46±3.31	48.94±1.52
		R	A	7.98±1.77	20.21±9.90	294.27±8.54	322.46±10.28	40.16±1.34	54.43±1.56	55.27±2.26
		139.10	B	5.14±1.77	12.41±5.10	362.87±16.18	380.43±13.01	23.86±2.06	46.85±1.50	48.49±1.59
2	2398.00	L	A	6.52±2.29	14.18±3.47	261.09±7.21	281.79±8.83	40.89±1.92	54.83±2.59	58.63±2.34
		141.45	B	5.50±1.37	7.62±2.91	356.14±14.43	369.26±13.40	26.95±1.45	50.44±1.68	50.50±1.72
		R	A	13.61±3.13	42.40±4.41	224.92±13.41	280.80±17.49	34.39±1.69	54.96±2.28	61.24±1.70
		149.64	B	6.20±1.95	37.76±7.71	241.98±11.58	285.94±11.38	41.51±2.05	58.86±1.64	59.43±2.38
3	2627.00	L	A	7.56±2.00	46.44±6.72	248.18±8.65	301.83±7.96	37.50±1.41	48.39±2.28	56.87±2.18
		154.88	B	8.51±1.94	31.73±7.06	293.03±13.13	333.27±8.17	31.99±2.44	51.34±1.28	55.96±1.77
		R	A	8.56±1.66	24.82±4.95	258.21±10.52	291.54±9.54	36.61±1.19	53.72±1.22	58.26±1.13
		134.64±10.20	B	1.14±0.29	18.89±5.59	312.00±18.53	335.27±14.39	40.15±6.61	49.80±1.45	53.54±1.05
Mean	2363.33±16.81	L	A	7.09±1.24	28.22±4.92	263.45±6.806	303.49±8.93	37.26±1.14	52.49±1.27	56.80±1.17
		139.09±9.87	B	7.03±0.99	18.82±4.25	337.33±13.07	362.60±9.97	30.28±1.43	48.50±1.29	51.98±1.04

† Mean± SE

Table C.5 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 60 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	8.67±3.46†	13.63±3.47	251.60±8.04	273.90±11.92	39.63±1.10	46.61±1.62	57.89±2.10
		174.28	B	2.95±1.23	15.48±5.89	254.60±11.21	273.04±9.18	38.44±2.10	56.03±1.99	61.48±1.68
1	3037.00	L	A	9.79±5.18	19.43±10.56	262.54±18.73	291.76±17.76	34.97±1.45	43.44±1.66	61.05±1.99
		174.34	B	6.95±1.79	12.20±1.87	359.27±10.78	378.42±9.75	28.34±1.16	44.35±1.30	52.63±1.41
		R	A	14.17±7.88	5.50±2.45	173.97±8.89	193.64±1.83	54.31±1.68	61.89±3.18	69.31±1.99
		242.04	B	2.55±0.80	3.12±0.48	188.93±10.82	194.60±10.31	62.14±4.08	72.15±5.78	81.28±2.30
2	3355.00	L	A	4.66±2.39	15.40±5.82	225.22±6.28	245.28±3.96	55.56±1.95	59.36±2.52	68.94±2.27
		251.12	B	2.98±1.13	4.96±3.03	240.56±12.74	249.50±12.40	53.95±3.95	63.02±2.01	61.28±1.71
		R	A	3.04±1.52	18.24±5.55	216.40±7.07	237.68±8.87	40.56±2.35	56.27±2.01	71.37±2.50
		214.39	B	11.30±2.40	8.83±3.77	252.92±3.87	273.05±2.86	34.19±1.90	53.22±1.56	61.14±1.79
3	3470.00	L	A	3.43±1.70	14.42±5.88	228.00±4.37	245.85±5.92	49.61±3.00	56.97±1.81	72.81±2.69
		224.42	B	12.20±4.82	8.37±1.74	237.72±4.98	258.29±4.22	35.11±1.61	49.05±2.80	62.36±1.56
		R	A	7.50±2.20	14.07±2.72	226.98±7.77	248.18±9.00	45.32±1.12	52.54±1.34	65.19±1.41
		210.24±19.67	B	5.13±1.31	9.64±2.80	233.05±9.79	246.49±11.53	44.59±2.40	57.50±1.63	69.23±1.42
Mean	3287.20±129.49	L	A	5.67±1.79	16.19±3.95	236.48±6.56	258.34±7.17	44.54±1.63	51.26±1.49	67.25±1.39
		216.63±22.50	B	7.37±1.91	8.51±1.46	279.14±16.06	294.03±16.65	37.18±1.70	51.81±1.51	59.00±1.00

† Mean± SE

Table C.6 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Bird at Age 100 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	5.98±2.75†	19.65±7.26	225.01±4.69	250.65±5.78	45.22±1.85	54.35±2.11	62.66±2.12
		378.85	B	2.85±1.37	11.70±3.04	211.16±21.33	228.73±17.56	60.00±3.79	75.38±2.66	74.82±2.87
1	4800.00	L	A	11.08±5.82	11.44±2.90	206.02±12.02	228.53±9.97	48.05±2.20	57.21±2.70	64.66±1.99
		392.11	B	0.43±0.43	17.30±3.27	263.11±10.97	280.84±12.98	42.83±5.54	61.11±3.32	66.24±1.42

† Mean± SE

Table C.7 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Control Birds at Age 150 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	0.29±0.22†	1.12±0.51	81.35±3.47	84.73±3.58	52.37±3.06	75.84±1.79	85.60±2.09
		454.54	B	-	4.34±1.92	169.32±2.07	173.75±2.50	68.73±3.28	68.73±3.28	80.42±2.21
1	6940.00	L	A	1.44±0.77	2.62±2.04	83.42±2.55	87.48±4.19	53.63±1.67	66.73±2.11	85.16±2.62
		476.40	B	-	4.81±2.01	151.61±5.83	156.49±5.48	-	61.36±2.17	84.96±2.71
		R	A	0.05±0.03	5.76±1.76	80.27±2.61	86.07±3.62	57.96±9.75	87.28±2.92	112.00±3.65
		474.42	B	0.98±0.34	6.87±1.76	160.99±3.76	168.84±2.94	58.00±4.45	78.16±3.00	88.41±2.66
2	6020.00	L	A	0.652±0.46	4.34±0.61	77.83±3.26	82.83±3.02	65.13±4.56	93.34±3.25	113.73±3.23
		513.17	B	-	3.47±1.35	168.29±5.46	171.84±5.39	-	69.09±4.21	83.21±2.32
		R	A	0.17±0.12	3.44±2.32	80.81±0.54	85.40±0.67	53.57±3.03	81.66±1.87	98.36±2.49
		464.48±9.94	B	0.61±0.23	5.91±1.31	164.16±2.58	170.68±2.07	58.00±4.45	74.65±2.34	84.14±1.75
Mean	6480.00±650.54	L	A	1.03±0.41	3.48±0.86	80.63±2.80	85.16±2.33	56.59±1.88	80.83±2.77	100.27±2.60
		494.78±18.38	B	-	4.11±1.16	160.39±4.34	164.53±4.14	-	64.49±2.19	84.08±1.78

† Mean± SE

C.2 - Selected Chickens

Table C.8 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 20 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	81.43±47.54†	81.09±34.12	1276.60±114.86	1439.10±64.14	17.95±0.78	22.44±0.68	22.95±0.66
		13.52	B	16.82±16.82	47.11±25.12	1226.48±88.13	1290.41±67.93	22.61±0.72	24.14±0.90	26.88±0.82
1	377.9	L	A	107.25±63.25	102.21±42.52	1158.30±114.55	1367.80±79.11	19.12±0.60	23.21±0.93	25.91±0.63
		13.83	B	6.73±6.73	22.99±11.75	1611.20±62.18	1640.90±66.73	14.79±1.02	16.93±0.57	17.96±0.54
		R	A	123.24±105.04	113.14±52.72	701.14±158.84	937.52±62.61	21.94±0.86	22.34±1.01	30.72±1.14
		20.22	B	21.03±16.62	65.19±15.97	924.90±44.09	1011.13±44.95	21.09±0.57	23.89±0.72	27.98±0.98
2	453.5	L	A	80.42±59.64	73.02±25.37	928.35±118.74	1081.80±47.61	19.28±0.45	23.30±0.64	25.14±0.85
		21.96	B	5.61±5.61	28.60±10.95	1027.40±18.59	1061.60±28.02	16.47±1.20	26.70±1.04	28.42±0.82
		R	A	68.42±41.56	41.50±17.06	906.82±161.22	1016.70±125.87	20.59±0.62	25.36±1.48	28.18±1.37
		19.31	B	-	14.02±9.92	1191.71±44.96	1206.29±35.38	-	24.16±0.95	25.71±0.94
3	471.50	L	A	56.08±30.37	43.74±25.75	1035.80±36.37	1135.60±39.00	16.80±0.38	19.27±0.59	23.56±0.81
		20.40	B	3.36±1.68	12.34±5.35	1124.97±91.48	1140.67±88.88	15.79±2.02	21.45±0.90	21.73±0.45
		R	A	92.67±38.57	81.88±22.56	992.34±106.17	1166.90±81.45	20.01±0.48	22.94±0.56	26.60±0.67
		17.68±2.10	B	13.63±8.01	44.41±11.53	1095.42±55.55	1153.46±47.74	21.61±0.46	24.02±0.48	26.93±0.53
Mean	434.30±28.67	L	A	83.28±31.29	75.43±18.35	1031.90±65.42	1190.60±49.50	18.63±0.31	22.44±0.48	24.84±0.47
		18.73±2.49	B	5.23±2.62	21.31±5.44	1254.52±95.90	1281.06±96.53	15.80±0.75	22.04±0.95	22.09±0.52

† Mean± SE

Table C.9 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 30 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	43.12±31.94†	39.15±12.47	529.34±44.26	611.60±19.63	30.04±0.78	36.94±0.73	36.41±1.08
		38.54	B	-	12.41±8.86	585.43±11.70	598.20±2.48	-	36.45±1.42	36.25±0.94
1	906.00	L	A	32.91±15.88	50.35±11.47	550.47±23.86	633.73±22.23	30.99±0.67	37.89±1.52	36.22±1.19
		39.90	B	0.94±0.62	21.98±6.98	672.07±8.01	695.00±12.08	19.85±2.11	34.20±1.65	36.56±0.89
		R	A	20.57±12.42	34.89±14.16	450.90±16.92	506.36±25.60	29.39±0.79	34.01±1.07	41.42±1.10
		41.72	B	21.28±14.89	25.88±12.41	709.54±23.76	756.70±3.55	27.42±1.11	31.91±0.85	30.36±0.71
2	1010.00	L	A	12.62±9.23	37.16±16.93	445.23±25.03	495.01±20.21	26.93±0.98	38.81±0.85	41.76±1.24
		45.33	B	11.35±3.13	29.08±5.61	645.18±25.06	685.61±17.87	33.14±1.93	35.35±1.32	34.47±1.05
		R	A	31.84±16.59	37.02±8.93	490.40±25.84	559.26±23.21	29.70±0.55	35.71±0.64	39.40±0.83
		40.13±1.59	B	10.64±8.64	19.15±7.34	647.49±37.42	677.27±45.90	27.42±1.11	33.59±0.85	33.13±0.68
Mean	958.00±52.00	L	A	22.76±9.29	43.76±9.89	497.85±23.95	564.37±27.11	29.39±0.61	38.36±0.85	39.25±0.94
		42.61±2.71	B	6.89±2.70	26.04±4.24	656.71±14.77	689.63±10.76	30.30±2.17	34.88±1.02	35.54±0.69

† Mean± SE

Table C.10 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 40 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	53.82±29.12†	62.80±25.06	331.82±63.63	448.44±20.16	40.47±1.03	47.50±0.92	58.36±1.65
		65.98	B	3.78±1.03	21.28±4.33	470.90±21.58	495.96±18.13	33.40±1.90	38.00±1.23	45.88±1.19
1	1272.00	L	A	10.43±2.41	26.64±1.77	367.76±5.35	404.84±5.38	36.73±1.70	47.65±1.62	42.13±1.49
		67.72	B	7.38±1.59	28.08±1.07	425.23±21.05	460.69±21.20	30.63±1.45	45.58±1.13	52.17±2.31
		R	A	12.20±45.60	45.60±21.78	398.07±43.28	455.86±21.40	43.06±1.09	50.62±0.96	55.94±1.46
		53.98	B	-	3.55±1.64	716.04±8.80	719.82±8.22	-	28.30±1.25	33.46±0.95
2	1292.00	L	A	26.34±14.59	46.63±18.21	448.74±52.13	521.69±24.17	41.18±1.62	42.11±0.99	47.68±1.90
		56.33	B	0.89±0.89	4.79±4.11	644.47±14.22	650.15±18.73	23.59±1.76	31.75±1.53	37.21±1.31
		R	A	23.58±13.96	33.51±17.15	290.32±34.30	347.41±11.67	42.00±1.92	48.49±1.81	54.41±1.29
		95.50	B	-	28.60±13.46	364.52±14.34	393.26±17.61	-	50.72±1.89	47.76±1.28
3	1167.90	L	A	24.02±12.34	26.59±11.25	313.37±26.08	363.99±13.30	39.74±1.31	50.51±1.75	58.62±2.12
		108.50	B	-	2.30±2.30	466.11±4.90	468.60±3.94	-	42.21±1.13	47.23±1.09
		R	A	29.44±10.96	47.75±12.41	344.06±28.737	421.26±14.14	36.83±0.80	44.72±0.97	50.56±1.10
		71.82±12.34	B	1.34±0.68	17.81±5.54	517.15±52.63	536.30±48.83	33.40±1.90	37.96±1.62	41.27±0.98
Mean	1414.33±132.46	L	A	20.69±6.56	33.58±7.42	377.01±22.91	431.28±17.24	35.29±1.11	42.48±0.82	43.80±0.93
		77.52±15.84	B	3.11±1.16	12.98±3.72	505.27±28.56	521.36±26.48	28.61±1.42	41.74±1.11	44.07±1.02

† Mean± SE

Table C.11 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 50 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	41.38±22.47†	24.82±10.62	245.85±27.60	312.46±14.00	45.91±1.11	54.72±1.32	64.86±1.96
		133.50	B	-	6.38±2.35	403.17±15.89	409.73±17.98	-	47.81±1.12	50.36±1.42
1	2433.00	L	A	3.90±1.79	19.15±5.30	249.99±13.60	273.04±9.11	48.30±1.75	55.66±1.81	67.84±2.13
		146.22	B	-	0.59±0.46	387.10±12.43	387.81±12.67	-	46.99±2.61	50.55±1.38
		R	A	21.54±11.42	25.22±5.79	246.09±10.78	292.85±7.90	48.80±1.06	51.82±1.00	59.87±1.54
		153.02	B	-	17.64±4.70	321.79±10.24	339.52±7.71	-	58.68±1.35	58.62±1.75
2	2555.00	L	A	4.81±1.81	21.08±2.89	198.69±6.62	224.58±4.24	59.33±1.50	64.62±1.45	70.21±1.45
		160.38	B	-	25.73±4.00	285.60±10.62	311.43±14.18	-	60.39±1.64	57.86±1.42
		R	A	17.84±9.80	20.13±9.16	272.05±19.15	310.02±11.32	46.23±1.37	52.95±1.64	68.66±2.43
		161.03	B	-	0.31±0.24	326.15±11.84	326.51±11.84	-	48.59±0.99	62.88±1.95
3	2920.90	L	A	22.51±13.62	21.67±8.06	290.28±19.40	334.56±7.55	43.29±1.35	48.70±1.32	57.70±1.56
		168.58	B	-	4.96±3.75	362.82±14.19	367.93±16.37	-	45.49±1.07	57.13±1.76
		R	A	26.29±8.45	23.49±4.70	254.25±10.81	304.03±6.25	47.15±0.68	53.16±0.74	63.95±1.15
		149.18±8.17	B	-	8.07±2.48	339.19±9.69	347.30±9.403	-	54.78±1.21	58.42±1.17
Mean	2636.00±146.59	L	A	10.47±4.69	20.71±3.21	244.18±9.63	275.37±7.79	51.34±1.21	57.84±1.13	65.69±1.09
		158.06±6.53	B	-	11.58±3.29	340.88±12.78	352.51±11.29	-	52.94±1.62	55.08±0.94

† Mean± SE

Table C.12 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 60 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	17.20±9.48†	18.48±6.87	186.47±11.82	222.15±9.30	51.69±1.25	55.37±1.04	67.25±2.17
		205.10	B	0.42±0.11	2.84±1.28	223.54±4.73	226.80±4.73	48.21±8.10	59.84±2.81	69.09±2.13
1	3065.00	L	A	20.31±10.09	29.18±11.04	192.59±7.63	242.09±13.68	47.76±1.06	53.26±1.71	66.24±3.24
		210.45	B	0.51±0.20	2.63±0.61	240.62±10.51	243.76±10.82	44.62±4.66	55.03±9.36	63.51±1.76
		R	A	13.10±6.61	18.06±5.43	186.81±9.08	217.97±7.31	55.21±1.42	61.81±2.07	76.85±2.38
		201.15	B	0.29±0.10	1.89±0.48	277.06±4.18	279.24±4.08	42.35±0.71	54.18±4.38	65.91±1.84
2	3445.00	L	A	0.20±0.11	1.82±0.51	213.47±5.70	215.49±5.52	57.73±3.89	63.11±4.03	83.82±2.16
		215.17	B	-	3.78±1.55	279.42±3.91	283.44±2.55	-	56.66±4.20	64.11±1.44
		R	A	14.41±6.11	15.00±3.55	197.71±8.42	227.13±6.29	55.49±1.05	59.03±1.11	72.20±1.91
		228.83	B	0.44±0.35	3.55±0.91	205.84±5.94	209.83±5.65	50.04±0.22	68.68±5.71	79.73±2.39
3	3570.00	L	A	7.88±3.21	24.43±8.18	140.85±6.050	173.16±7.52	54.40±1.42	68.03±3.14	83.46±1.77
		235.35	B	0.30±0.14	4.71±1.00	197.81±4.81	202.83±5.00	55.74±4.07	59.78±2.21	70.66±2.69
		R	A	14.84±4.18	17.07±3.00	190.69±5.55	222.60±4.32	54.04±8.14	57.91±0.84	72.14±1.33
		211.69±8.64	B	0.38±0.11	2.65±0.52	240.23±6.33	243.25±6.18	47.43±2.97	61.80±2.70	71.41±1.39
Mean	3360.00±151.85	L	A	9.33±3.45	18.99±4.86	178.70±5.94	207.02±6.80	51.03±0.93	60.69±1.84	77.56±1.73
		220.32±7.63	B	0.32±0.10	3.99±0.65	220.50±7.30	224.81±7.25	50.80±3.47	57.68±2.69	66.47±1.32

† Mean± SE

Table C.13 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 100 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	2.43±1.49†	23.77±7.96	121.93±8.12	148.13±7.54	49.18±1.25	59.43±1.49	82.24±2.33
		333.96	B	0.86±0.40	8.79±2.50	154.95±5.60	164.60±4.01	56.31±1.91	65.84±1.94	78.24±2.05
1	5500.00	L	A	6.08±3.07	20.77±2.09	83.91±4.80	110.77±3.56	67.39±1.91	80.34±3.12	93.32±2.16
		378.87	B	2.57±0.96	15.51±3.55	138.11±4.57	156.20±3.772	52.44±1.95	74.99±2.12	79.94±2.33
		R	A	1.98±0.81	6.41±3.52	119.49±5.31	127.87±5.17	50.01±1.54	68.67±1.65	91.22±2.67
		394.60	B	0.39±0.22	2.63±1.31	127.80±7.60	130.81±7.16	61.67±5.04	87.49±3.39	97.80±2.75
2	5600.00	L	A	2.40±1.34	7.98±3.94	108.07±5.40	118.46±3.96	52.92±1.66	61.37±1.54	93.46±2.61
		409.58	B	0.28±0.17	2.84±0.81	161.13±4.91	164.25±4.77	34.83±2.21	59.36±4.78	80.60±1.93
		R	A	2.25±0.83	13.46±4.13	93.78±4.19	109.49±3.75	70.82±2.70	74.66±1.61	106.97±2.43
		393.80	B	0.24±0.13	1.22±0.40	177.50±5.08	178.96±4.86	54.28±8.37	53.36±3.58	75.72±1.66
3	6250.00	L	A	2.97±1.08	18.52±6.50	105.64±5.70	127.13±3.08	61.96±1.56	76.61±1.97	101.57±2.82
		425.46	B	0.89±0.45	3.90±2.10	190.06±7.77	194.85±9.74	44.65±6.96	56.63±3.30	76.40±7.43
		R	A	2.20±0.55	13.49±2.91	108.11±3.70	123.80±3.70	56.91±1.66	67.28±1.17	92.98±1.75
		374.12±20.08	B	0.46±0.14	3.85±1.07	154.49±5.78	158.81±5.54	57.41±2.70	72.30±2.92	84.65±1.59
Mean	5783.33±235.11	L	A	3.35±0.89	15.23±3.38	102.47±3.54	121.05±2.24	61.88±1.16	74.36±1.58	96.15±1.53
		404.64±13.67	B	1.50±0.51	2.05±0.27	157.11±5.97	167.66±4.87	49.97±2.05	69.93±2.04	78.94±2.72

† Mean± SE

Table C.14 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in Selected Birds at Age 150 Days

Bird No.	Killing Wt.(gram)	Muscle Wt.(gram)	Region Area	Fibre Type No./mm^2 Red(SO)	Inter.(FOG)	White(FG)	Total No./mm^2	Fibre Type Diameter μm Red(SO)	Inter.(FOG)	White(FG)
		R	A	4.08±2.76†	15.46±8.09	82.81±7.87	102.35±5.03	62.90±1.02	73.41±1.55	103.80±3.43
		492.22	B	0.81±0.18	2.43±1.06	143.11±4.25	145.62±3.64	67.79±3.38	74.07±2.62	88.91±2.11
1	7150.00	L	A	5.85±3.53	10.68±5.34	91.93±5.65	108.46±4.08	75.15±1.74	76.29±1.64	111.25±2.40
		521.25	B	-	1.03±0.49	143.92±3.58	144.98±3.68	-	75.51±2.37	85.29±2.22

† Mean± SE

Table C.15 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in the Most Asymmetrical Selected Birds at Age 50 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	0.83±0.53†	5.09±2.47	378.83±5.63	384.75±5.42	42.64±1.18	49.08±1.32	52.08±0.98
		108.08	B	-	4.68±3.18	397.64±9.81	402.39±10.79	-	44.54±2.07	45.32±1.16
1	2160	L	A	4.35±2.14	42.22±14.89	325.80±17.43	372.37±8.54	41.54±1.55	46.03±1.57	55.04±1.29
		119.14	B	-	2.30±1.51	421.79±8.57	424.18±8.93	-	43.90±5.70	48.66±0.71
		R	A	7.89±6.17	26.52±11.47	224.34±16.26	258.76±12.11	50.07±1.62	58.73±1.47	67.84±1.77
		106.35	B	-	3.84±1.38	321.26±20.79	325.16±19.96	-	53.30±1.31	54.20±1.22
2	1990	L	A	9.55±4.92	21.07±9.87	297.07±16.33	327.69±7.53	51.53±1.25	53.18±1.38	63.93±1.77
		115.12	B	-	8.75±6.33	380.71±16.23	389.58±11.63	-	52.41±1.45	55.11±1.22
		R	A	4.13±1.66	32.58±10.52	241.71±16.74	278.42±7.32	55.98±1.29	57.98±1.11	71.09±1.42
		115.97	B	-	6.70±2.33	330.42±6.85	337.19±6.35	-	51.51±1.74	54.06±1.30
3	2250	L	A	4.30±2.48	23.58±10.01	249.86±8.68	277.74±7.70	42.10±1.90	50.87±1.79	63.10±1.39
		126.75	B	-	10.96±3.12	329.45±5.80	340.47±3.95	-	52.68±1.93	57.82±1.41
		R	A	4.14±1.98	21.19±5.31	283.96±12.66	309.29±9.33	51.16±1.04	56.76±0.87	63.96±1.08
	2133.33±76.23	110.13±2.96	P	-	5.05±1.31	347.50±10.10	352.57±9.93	-	51.32±1.00	51.44±0.77
Mean		L	A	6.17±2.03	28.96±6.72	290.31±9.42	325.44±7.22	46.80±1.03	50.13±0.49	61.29±0.94
		120.34±3.41	B	-	7.66±2.14	371.30±9.65	378.99±8.52	-	50.30±1.07	53.89±0.73

† Mean± SE

Table C.16 - Number and Diameter of Fibre Types in the Right and Left Side of the Pectoralis Muscle in the Most Asymmetrical Selected Birds at Age 100 Days

Bird	Killing	Muscle	Region	Fibre Type No./mm^2			Total	Fibre Type Diameter μm		
No.	Wt.(gram)	Wt.(gram)	Area	Red(SO)	Inter.(FOG)	White(FG)	No./mm^2	Red(SO)	Inter.(FOG)	White(FG)
		R	A	4.12±2.34†	6.22±2.17	125.51±4.26	135.75±3.33	63.11±1.15	71.49±1.33	89.30±1.67
		382.72	B	0.37±0.20	1.45±0.38	169.09±3.71	170.91±3.79	61.89±6.32	62.01±4.22	78.74±2.34
1	6340.00	L	A	14.47±6.64	11.88±3.59	118.40±5.71	134.76±6.17	61.41±1.27	73.96±1.46	86.25±2.47
		421.40	B	-	2.70±0.74	158.93±2.63	161.66±2.82	-	57.16±2.54	79.92±2.22
		R	A	8.44±4.35	8.72±2.93	107.34±3.06	124.51±6.20	60.42±1.37	72.38±1.18	90.66±2.38
		448.29	B	-	1.26±0.32	133.46±2.58	134.74±2.66	-	83.79±2.90	91.54±1.92
2	6350.00	L	A	2.75±1.52	5.36±2.68	101.26±3.93	109.37±3.08	57.80±1.76	75.25±2.74	93.95±1.60
		482.18	B	0.21±0.15	2.13±0.54	139.93±3.47	142.27±3.58	43.64±6.31	75.29±4.67	88.66±1.90
		R	A	1.56±0.80	10.40±3.70	104.11±3.994	116.08±2.89	65.12±2.16	74.58±2.03	99.39±2.57
		341.47	B	0.27±0.10	1.92±0.57	149.85±3.33	152.04±2.99	62.95±5.02	73.42±2.75	83.68±2.06
3	5800.00	L	A	9.89±5.41	4.87±1.78	81.74±3.30	96.49±3.92	74.76±1.18	75.74±1.87	93.14±2.02
		366.90	B	1.38±0.61	1.19±0.22	140.95±3.20	143.52±3.28	56.55±2.04	82.21±14.36	89.44±1.95
		R	A	5.12±1.90	8.30±1.66	112.77±2.51	126.15±2.94	62.59±0.96	72.96±0.93	93.26±1.34
	6163.33±181.69	390.83±31.10	B	0.20±0.08	1.51±0.24	150.32±3.25	152.03±3.28	62.42±3.88	74.42±2.22	84.63±1.29
Mean		L	A	9.34±3.06	7.64±1.71	97.79±3.06	114.79±3.56	65.23±1.08	74.98±0.53	91.33±1.18
		423.49±33.29	B	0.54±0.24	2.00±0.32	146.83±2.39	149.38±2.45	54.24±2.17	68.69±3.25	86.32±1.21

† Mean± SE

APPENDIX D

APPENDIX D

D.1 ANATOMICAL MEASUREMENTS ON THE ASYMMMETRICAL SKELETON AND PECTORALIS MUSCLE OF THE SELECTED ASYMMETRY CHICKENS BY ULTRASONIC ULTRASONIC METHOD

Table D.1 - Keel Depth Measurment on Live Chickens by Ultrasonic Method on Live Chickens

Birds		C	D	E	F	J	K	L	O	P
50 Days†		–	–	–	–	–	–	–	–	–
57 Days	Live Weight	2850	3030	3020	3230	2690	2870	3000	3250	3230
	Right	26	26	27	26	26	25	26	27	25
	Left	24	23.5	25	24	24.5	23	24	25.5	24
	R/L %	108.3	110.6	108.0	103.8	106.1	108.7	108.3	105.9	104.2
64 Days	Live Weight	3580	3630	3530	3970	3390	3630	3750	3960	3970
	Right	30	34	30	28	28	27	30	29	29
	Left	28	30	28	25	26	25	27	28	27
	R/L %	107.1	113.3	107.1	112.0	107.7	108.0	108.1	107.4	107.4
70 Days	Live Weight	4120	4120	3890	4340	3900	4170	4320	4400	4460
	Right	34	34	31	33	30	33	31	34	33
	Left	30	31	28	28	29	29	30	30	31
	R/L %	113.3	109.7	110.7	117.9	103.4	113.8	103.3	113.3	106.5
77 Days	Live Weight	4680	4750	4100	4750	4445	4810	5070	5070	5140
	Right	37	35	33	33	34	33	32	35	34
	Left	35	33	29	29	32	30	31	32	31
	R/L %	105.7	106.1	113.8	113.8	106.3	110.0	103.2	109.4	109.7
84 Days	Live Weight	5100	5180	–	5150	4930	5320	5580	–	5560
	Right	38	38	–	34	34	34	34	–	35
	Left	35	36	–	30	32	32	32	–	33
	R/L %	108.6	105.6	–	113.3	106.3	106.3	106.3	–	106.1
91 Days	Live Weight	5400	5500	–	5410	5300	5250	6000	–	5590
	Right	40	40	–	37	36	35	36	–	35
	Left	37	37	–	33	34	33	34	–	33
	R/L %	108.1	108.1	–	112.1	105.9	106.1	105.9	–	106.1
98 Days	Live Weight	–	5750	–	–	5190	5270	6350	–	5370
	Right	–	41	–	–	43	36	40	–	37
	Left	–	36	–	–	37	32	35	–	32
	R/L %	–	113.9	–	–	116.2	112.5	114.3	–	115.6

†See table D.2 for this age.

Muscles thickness in millimeter for right and left sides. This sign (–) indicate that there was no data obtained becuase the bird was dead.

Table D.2 - Some Measurements on the Chickens Pectoralis Muscles at Age 50 Days

Birds		A	B	G	I	Q	N	R	S
Live Weight		2100	2410	2400	2200	2490	2480	2250	2480
Muscle Weight	R	121.72	124.91	124.00	120.83	127.26	116.42	123.54	125.74
	L	128.80	130.05	129.73	131.68	136.79	119.05	129.23	136.70
Percentage	R/L	94.5%	96.0%	95.6%	91.8%	93.0%	97.8%	95.6%	95.1%
Keel Depth on	R	26	24	28	24	25	24	24	25
Live Bird	L	22	20	24	21	22	22	20	21
Percentage	R/L	118.2%	120.0%	116.7%	114.3%	113.6%	109.1%	120.0%	119.0%
Pectoralis Muscle	R	18	17	20	19	18	18	17	17
Thickness	L	20	19	23	22	21	20	20	19
Percentage	R/L	90.0%	89.5%	86.7%	86.4%	85.7%	90.0%	85.0%	89.5%
Pectoralis Muscle	R	175	168	170	175	190	172	180	170
Length	L	185	177	170	175	195	172	185	185
Percentage	R/L	94.59%	100.6%	100.0%	100.0%	100.0%	100.0%	97.30%	91.89%
Pectoralis Muscle	R	54.25	58.45	64.10	53.00	60.15	53.75	61.00	58.55
Width	L	59.67	63.45	67.90	58.75	65.55	62.30	65.20	63.00
Percentage	R/L	90.9%	92.1%	94.4%	90.2%	95.6%	86.3%	93.6%	92.9%
Longest Fasciculus	R	57.65	45.35	55.70	56.70	61.00	59.25	51.00	55.55
	L	65.70	51.70	59.85	60.55	64.85	63.35	56.25	63.35
Percentage	R/L	87.7%	87.7%	93.1%	93.6%	94.1%	93.5%	90.7%	87.7%
Shortest Fasciculus	R	34.50	41.00	52.65	42.80	44.10	49.60	42.45	40.25
	L	39.80	42.50	53.40	47.90	45.85	49.55	43.80	40.00
Percentage	R/L	86.7%	96.5%	98.6%	89.4%	96.2%	100.1%	97.7%	100.6%
Ribs Angle with	R	160	140	136	152	145	132	154	160
the Keel	L	138	135	110	116	138	124	124	115
Percentage	R/L	115.9%	105.3%	123.6%	131.0%	105.1%	106.5%	124.2%	139.1%

Table D.3 Weight and Length of Some Bones at Age 50 Days

Birds		A		B		G		I	
Bone		Right	Left	Right	Left	Right	Left	Right	Left
Coracoid	Weight	2.04	1.95	1.88	2.04	2.03	1.95	1.92	1.83
	Length	53.55	53.80	48.10	49.00	51.25	50.85	51.55	51.50
Scapula	Weight	0.94	0.99	1.01	1.04	1.24	1.10	0.93	0.97
	Length	68.35	69.55	65.3	66.40	68.25	67.75	64.10	64.40
Clavicle	Length	45.60	46.50	43.00	44.10	42.80	44.55	42.50	43.35
P & A X Process	Weight	0.60	0.62	0.42	0.45	0.56	0.54	0.48	0.51
P X Process	Length	53.15	54.35	52.20	50.15	49.15	48.85	53.90	55.40
A X Process	Length	30.70	31.70	28.45	29.35	32.30	30.95	32.15	33.65
Keel	Depth	23.30	21.35	23.15	20.75	21.80	20.70	22.20	20.10
	Width	29.45	32.20	32.75	34.90	30.00	32.65	30.35	32.55
	Length	36.45	–	35.70	–	37.20	–	39.50	–

continue ....

Table D.3 – continue ...

Birds		N		Q		R		S	
Bone		Right	Left	Right	Left	Right	Left	Right	Left
Coracoid	Weight	1.84	1.93	2.16	2.25	1.86	1.81	2.06	1.95
	Length	50.35	50.65	55.00	54.70	49.45	49.15	51.85	52.20
Scapula	Weight	0.88	0.97	1.07	1.15	1.00	1.00	1.14	1.13
	Length	59.10	66.40	70.35	71.45	66.30	67.00	66.10	67.75
Clavicle	Length	40.70	38.00	44.35	45.90	41.55	42.40	46.80	47.95
P & A X Process	Weight	0.60	0.63	0.51	0.53	0.38	0.41	0.49	0.53
P X Process	Length	53.80	55.00	56.00	55.80	50.35	48.80	49.45	49.80
A X Process	Length	29.35	30.80	33.40	32.30	28.45	28.00	27.25	27.25
Keel	Depth	23.70	21.50	24.05	21.30	25.45	22.55	22.70	20.60
	Width	30.15	33.40	32.25	34.95	33.55	35.60	28.55	30.95
	Length	31.55	–	45.00	–	37.80	–	32.85	–

Table D.4 - Weight and Length of the Chicken's Ribs Aged 50 Days

Birds		A		B		G		I	
Rib No.		Right	Left	Right	Left	Right	Left	Right	Left
1st	Weight	0.03	0.04	–	–	0.06	0.06	0.11	0.09
	Length	–	–	–	–	23.95	23.50	28.00j	27.60
2nd	Weight	0.05	0.08	0.05	0.05	0.12	0.12	0.19	0.18
	Length	–	–	23.35	22.25	28.25	29.30	31.65	33.05
3rd	Weight	0.13	0.13	0.10/0.35†	0.09/0.35	0.18/0.06	0.17/0.06	0.20/0.06	0.20/0.10
	Length	30.25	31.55	29.10/16.95	29.10/17.00	31.70/20.25	33.15/19.40	32.15/22.60	33.70/24.10
4th	Weight	0.19/0.05	0.16/0.06	0.16/0.11	0.20/0.09	0.23/0.10	0.23/0.10	0.24/0.11	0.22/0.12
	Length	35.90/–	36.25/–	33.35/24.12	33.90/24.60	30.75/25.90	33.80/25.00	33.70/29.00	35.15/29.25
5th	Weight	0.20/0.08	0.21/0.09	0.22/0.14	0.21/0.13	0.29/0.14	0.29/0.14	0.31/0.13	0.27/0.13
	Length	36.50/–	37.10/–	34.65/29.65	35.10/29.95	33.30/31.15	35.80/30.20	34.00/32.35	34.60/32.35
6th	Weight	0.25/0.13	0.24/0.13	0.28/0.13	0.26/0.13	0.30/0.13	0.20/0.14	0.28/0.09	0.23/0.09
	Length	37.20/–	38.05/–	35.75/30.59	36.82/32.60	34.10/34.65	36.65/33.05	34.15/32.90	34.45/33.10
7th	Weight	0.25/0.11	0.25/0.11	0.30/0.11	0.30/0.11	–/0.07	–/0.05	–	–
	Length	37.25/35.95	37.80/27.25	36.75/34.20	38.35/34.20	–/33.75	–/29.15	–	–
Birds		Q		N		R		S	
Rib No.		Right	Left	Right	Left	Right	Left	Right	Left
1st	Weight	0.04	0.06	0.04	0.03	0.04	0.04	0.08	0.10
	Length	24.30	24.20	20.45	19.65	21.00	21.80	22.95	23.95
2nd	Weight	0.10	0.08	0.08	0.08	0.14	0.12	0.11	0.12
	Length	30.65	28.95	23.85	23.85	30.10	27.75	28.45	29.35
3rd	Weight	0.18/0.03	0.15/0.04	0.15/0.04	0.18/0.05	0.21/0.05	0.20/0.04	0.20/0.03	0.17/0.05
	Length	32.60/15.05	33.00/16.15	30.95/20.65	32.50/20.25	34.20/18.75	34.55/18.10	34.50/16.2	34.80/18.75
4th	Weight	0.21/0.09	0.19/0.09	0.22/0.07	0.24/0.09	0.23/0.11	0.23/0.11	0.25/0.09	0.22/0.11
	Length	35.00/24.10	35.65/22.90	32.45/24.00	33.25/26.65	34.10/25.60	34.15/25.75	34.40/24.10	35.90/25.15
5th	Weight	0.24/0.15	0.22/0.15	0.25/0.11	0.27/0.12	0.26/0.13	0.25/0.13	0.26/0.14	0.25/0.14
	Length	35.30/29.85	34.65/29.10	34.25/30.10	34.60/30.35	34.50/31.20	35.15/30.90	34.80/30.25	35.95/30.30
6th	Weight	0.34/0.15	0.33/0.16	0.28/0.12	0.26/0.10	0.35/0.14	0.28/0.13	0.33/0.14	0.31/0.14
	Length	34.70/35.75	37.15/35.90	34.85/31.50	35.00/32.75	33.30/33.80	34.10/33.80	36.45/33.75	37.40/30.95
7th	Weight	0.28/0.14	0.25/0.15	0.20/0.04	0.20/0.08	0.23/0.06	0.25/0.08	0.28/0.09	0.26/0.08
	Length	31.55/34.15	36.50/33.20	38.90/27.15	38.50/32.25	36.15/32.75	37.55/30.90	36.20/30.95	36.70/30.00

†The first number indicates the weight or length of vertebral rib where the second number for the sternal rib

Rib's weight in gram and the length in millimeter.

Table D.5 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird A)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	20.0	24.0	204	45.5	29.0
	L	25.0	26.0	260	59.5	32.0
	R/L %	80.0	92.3	78.5	76.5	90.6
2nd Rib	R	26.3	28.0	318	44.0	33.0
	L	28.8	30.0	353	49.0	38.0
	R/L %	91.3	93.3	90.1	89.8	86.8
3rd Rib	R	38.8	30.0	490	29.5	35.0
	L	37.5	30.0	577	34.0	39.0
	R/L %	103.5	100.0	84.9	86.8	89.7
4th Rib	R	48.8	32.0	515	19.5	24.0
	L	48.8	35.0	666	36.5	37.0
	R/L %	100.0	91.4	77.3	53.4	64.9
5th Rib	R	51.3	33.0	545	22.5	36.0
	L	48.8	35.0	576	26.0	39.0
	R/L %	105.1	94.3	94.6	86.5	92.3
6th Rib	R	51.3	34.0	613	24.5	38.0
	L	50.0	36.0	618	29.0	41.0
	R/L %	102.5	94.4	99.2	84.5	92.7
7th Rib	R	53.8	33.0	555	30.0	39.0
	L	47.5	35.0	647	41.2	41.5
	R/L %	113.3	94.3	85.8	72.8	94.0

Table D.6 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird B)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	18.6	20.0	195	46.5	32.0
	L	18.6	23.0	227	48.0	33.0
	R/L %	100.0	87.0	85.9	96.9	97.0
2nd Rib	R	25.1	22.0	212	47.5	35.0
	L	26.2	26.0	279	53.0	37.0
	R/L %	95.8	84.6	86.7	89.6	94.6
3rd Rib	R	49.7	28.0	409	33.5	35.0
	L	48.6	31.0	500	38.0	38.0
	R/L %	102.3	90.3	81.8	88.2	92.1
4th Rib	R	49.7	30.0	482	25.0	36.0
	L	47.1	33.0	589	30.5	38.0
	R/L %	105.5	90.9	81.8	82.0	94.7
5th Rib	R	50.0	30.0	462	25.5	36.0
	L	48.6	33.0	546	29.0	39.0
	R/L %	102.9	90.9	84.6	87.9	92.3
6th Rib	R	50.0	34.0	532	21.0	37.0
	L	49.0	36.0	606	29.0	40.0
	R/L %	102.0	94.4	87.8	72.4	92.5
7th Rib	R	54.3	35.0	587	31.5	40.0
	L	51.4	38.0	650	41.0	46.0
	R/L %	105.5	92.1	90.3	76.8	87.0

Table D.7 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird G)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	21.0	23.0	178	44.0	30.0
	L	20.6	26.0	203	46.5	31.0
	R/L %	101.9	88.5	87.7	94.6	96.8
2nd Rib	R	28.3	26.0	266	33.0	32.0
	L	25.6	31.0	320	47.5	36.0
	R/L %	110.5	83.9	83.1	69.5	88.9
3rd Rib	R	46.7	27.0	482	26.0	37.0
	L	45.0	29.0	533	35.0	39.0
	R/L %	103.8	93.1	90.4	74.3	94.9
4th Rib	R	48.9	28.0	503	21.0	35.0
	L	48.9	31.0	551	34.0	38.0
	R/L %	100.0	90.3	91.3	61.8	92.1
5th Rib	R	51.1	28.0	456	24.0	37.0
	L	50.6	31.0	586	34.5	45.0
	R/L %	101.0	90.3	77.8	69.6	83.2
6th Rib	R	–	–	–	–	–
	L	–	–	–	–	–
	R/L %	–	–	–	–	–
7th Rib	R	–	–	–	–	–
	L	–	–	–	–	–
	R/L %	–	–	–	–	–

Table D.8 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird I)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	23.0	25.0	238	36.0	33.0
	L	24.0	27.0	269	42.0	35.0
	R/L %	95.8	92.6	88.5	85.7	94.3
2nd Rib	R	42.0	25.0	428	32.0	38.0
	L	42.0	26.0	452	39.5	40.0
	R/L %	100.0	96.2	94.7	81.0	95.0
3rd Rib	R	45.0	28.0	429	27.5	35.0
	L	46.5	30.0	449	33.0	37.0
	R/L %	96.8	93.3	95.5	83.3	94.6
4th Rib	R	47.0	28.0	450	22.5	35.0
	L	47.0	31.0	544	34.5	40.0
	R/L %	100.0	90.3	82.7	65.2	87.5
5th Rib	R	48.0	28.0	476	25.5	34.0
	L	50.0	32.0	576	28.0	42.0
	R/L %	96.0	87.5	82.6	91.1	81.0
6th Rib	R	49.0	30.0	549	26.0	38.0
	L	51.0	32.0	603	29.0	40.0
	R/L %	96.1	93.8	91.0	89.7	95.0
7th Rib	R	–	–	–	–	–
	L	–	–	–	–	–
	R/L %	–	–	–	–	–

Table D.9 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird Q)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	21.3	20.0	196	48.0	27.0
	L	21.3	25.0	212	50.0	27.0
	R/L %	100.0	74.1	92.4	96.0	100.0
2nd Rib	R	40.0	25.0	327	47.5	35.0
	L	39.4	27.0	346	52.0	37.0
	R/L %	101.6	92.4	94.5	91.3	94.6
3rd Rib	R	45.6	25.0	455	34.5	38.0
	L	46.3	29.0	487	41.5	38.0
	R/L %	98.6	86.2	93.4	83.1	100.0
4th Rib	R	47.5	27.0	540	22.5	39.0
	L	49.4	30.0	656	29.0	41.0
	R/L %	92.2	90.0	82.3	77.6	95.1
5th Rib	R	58.8	30.0	530	20.5	36.0
	L	58.8	33.0	597	22.5	39.0
	R/L %	100.0	90.0	88.8	91.1	92.3
6th Rib	R	51.3	34.0	481	18.0	33.0
	L	53.8	37.0	573	24.5	37.0
	R/L %	95.3	91.9	83.9	73.5	89.2
7th Rib	R	58.8	34.0	512	21.0	33.0
	L	55.6	38.0	623	27.0	36.0
	R/L %	105.8	89.5	82.2	77.8	91.7

Table D.10 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird N)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	–	–	–	–	–
	L	–	–	–	–	–
	R/L %	–	–	–	–	–
2nd Rib	R	–	–	–	–	–
	L	–	–	–	–	–
	R/L %	–	–	–	–	–
3rd Rib	R	39.1	27.0	296	24.0	28.0
	L	38.8	30.0	479	36.5	38.0
	R/L %	100.8	90.0	61.8	65.8	73.7
4th Rib	R	41.6	28.0	410	21.0	31.0
	L	43.8	32.0	523	33.5	40.0
	R/L %	95.0	87.5	69.1	62.7	77.5
5th Rib	R	42.9	30.0	451	20.5	32.0
	L	42.5	35.0	518	26.5	38.0
	R/L %	100.9	85.7	87.1	77.4	84.2
6th Rib	R	43.8	33.0	517	21.5	35.0
	L	42.5	35.0	587	26.0	40.0
	R/L %	103.1	94.3	88.1	82.7	87.5
7th Rib	R	42.0	33.0	554	30.0	45.0
	L	43.8	36.0	657	38.0	50.0
	R/L %	95.9	91.7	84.3	79.0	90.0

Table D.11 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird R)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	23.8	20.0	124	53.0	29.0
	L	25.0	22.0	173	55.0	31.0
	R/L %	95.2	20.9	71.7	96.4	93.5
2nd Rib	R	30.8	14.0	311	46.0	34.0
	L	31.3	16.0	332	50.0	39.0
	R/L %	98.4	87.5	93.7	92.0	87.2
3rd Rib	R	46.0	24.0	506	35.0	40.0
	L	47.5	26.0	511	45.0	45.0
	R/L %	96.8	92.3	99.0	77.8	88.9
4th Rib	R	47.5	27.0	429	26.0	38.0
	L	50.0	30.0	488	36.0	41.0
	R/L %	95.0	90.0	87.9	72.2	92.7
5th Rib	R	50.0	27.0	409	20.0	39.0
	L	50.6	30.0	529	33.0	42.0
	R/L %	98.8	90.0	77.3	60.6	92.8
6th Rib	R	53.0	30.0	545	25.0	38.0
	L	52.9	34.0	590	34.0	41.0
	R/L %	100.2	88.2	92.4	73.5	92.7
7th Rib	R	53.5	30.0	638	27.0	33.0
	L	52.0	37.0	684	34.0	45.0
	R/L %	100.9	81.1	93.3	79.4	73.3

Table D.12 - Some Measurements on the Chicken's Ribs Aged 50 Days (Bird S)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	21.3	20.0	172	43.0	30.0
	L	21.3	24.0	193	47.5	30.0
	R/L %	100.0	83.3	89.1	90.5	100.0
2nd Rib	R	26.7	28.0	305	42.0	31.0
	L	28.0	28.0	391	48.5	33.0
	R/L %	95.4	100.0	78.0	86.6	93.9
3rd Rib	R	44.0	27.0	483	29.0	36.0
	L	46.7	29.0	513	31.5	39.0
	R/L %	106.1	93.1	94.2	92.1	92.3
4th Rib	R	50.7	30.0	475	23.0	34.0
	L	48.0	33.0	564	34.0	39.0
	R/L %	105.6	90.9	84.2	67.6	87.2
5th Rib	R	53.3	32.0	500	22.0	32.0
	L	53.3	35.0	569	34.0	38.0
	R/L %	100.0	91.4	87.9	64.7	84.2
6th Rib	R	53.3	35.0	502	19.5	33.0
	L	56.0	38.0	563	31.0	35.0
	R/L %	95.2	92.1	89.2	62.9	94.3
7th Rib	R	53.3	35.0	578	20.5	34.0
	L	54.7	39.0	686	33.0	38.0
	R/L %	97.4	89.7	84.3	62.1	89.5

Table D.13 - Some Measurements on the Chickens Pectoralis Muscles at Age 100 Days

Birds		D	J	K	L	P	Z
Live Weight(g)		5880	5230	5420	6500	5400	4700
Muscle Weight	R	405.88	279.52	341.06	447.60	410.47	312.28
	L	432.77	327.89	363.80	495.82	455.84	338.46
Percentage	R/L	93.8%	90.7%	93.7%	90.3%	90.0%	89.6%
Keel Depth on	R	42	44	37	41	38	40
Live Bird	L	38	40	34	37	33	36
Percentage	R/L	110.5%	110.0%	108.8%	114.8%	115.2%	111.1%
Pectoralis Muscle	R	31	23	34	32	33	31
Thickness	L	35	28	36	35	35	34
Percentage	R/L	88.66%	82.14%	94.41%	91.43%	94.43%	91.18%
Pectoralis Muscle	R	235	240	231	220	240	221
Length	L	247	253	240	233	249	250
Percentage	R/L	95.14%	94.86%	96.25%	94.42%	96.39%	88.40%
Pectoralis Muscle	R	115	118	120	113	125	110
Width	L	123	125	128	120	133	121
Percentage	R/L	93.5%	94.4%	93.8%	94.2%	94.4%	90.9%
Longest Fasciculus	R	67.30	78.50	79.45	70.20	76.30	67.30
	L	76.10	88.90	85.35	77.10	84.85	74.30
Percentage	R/L	88.4%	88.3%	93.1%	91.1%	89.9%	90.6%
Shortest Fasciculus	R	60.10	72.40	74.10	62.30	67.30	60.10
	L	71.10	75.80	77.35	65.90	77.10	71.00
Percentage	R/L	84.5%	95.5%	95.8%	94.5%	87.3%	84.6%
Breast Angle	R	149	160	140	146	150	145
	L	114	118	126	123	112	116
Percentage	R/L	130.7%	135.6%	111.1%	118.7%	133.9%	125.0%

Table D.14 - Weight and Length of Some Chickens Bones at Age 100 Days

Birds		D		J		K	
Bone		Right	Left	Right	Left	Right	Left
Coracoid	Weight	4.77	4.65	4.31	4.25	4.62	4.69
	Length	67.00	68.40	69.75	68.30	72.40	73.45
Scapula	Weight	2.44	2.55	2.23	2.28	2.17	2.66
	Length	91.75	92.80	95.50	95.60	93.10	92.85
Clavicle	Length	57.70	58.90	59.40	60.45	56.90	58.60
P & A X Process	Weight	–	–	–	–	–	–
P X Process	Length	70.85	73.75	71.35	73.65	71.40	72.05
A X Process	Length	35.65	36.20	39.45	36.35	35.55	34.50
Keel	Depth	37.15	33.45	37.35	34.40	34.00	30.90
	Width	48.00	50.30	47.80	49.95	45.05	47.20
	Length	72.85	–	77.70	–	78.80	–

continue ....

Table D.14 – continue ...

Birds		L		P		Z	
Bone		Right	Left	Right	Left	Right	Left
Coracoid	Weight	5.45	5.52	4.62	4.46	5.60	5.00
	Length	72.65	74.85	71.05	71.65	70.60	70.95
Scapula	Weight	2.86	3.23	2.48	2.32	2.60	2.81
	Length	96.90	98.15	96.75	95.45	91.20	92.75
Clavicle	Length	55.85	56.30	60.75	62.45	59.15	58.35
P & A X Process	Weight	–	–	–	–	–	–
P X Process	Length	69.65	70.10	74.75	75.95	62.20	64.60
A X Process	Length	33.15	33.75	32.90	32.65	26.70	28.55
Keel	Depth	36.00	33.35	32.15	29.55	38.70	34.65
	Width	44.00	47.75	43.85	45.50	46.35	48.80
	Length	71.25	–	74.20	–	50.90	–

Table - D.15 Weight and Length of the Chickens Ribs at Age 100 Days

Birds		D		J		K	
Rib No.		Right	Left	Right	Left	Right	Left
1st	Weight	0.09	0.01	0.12	0.11	0.22	0.22
	Length	30.30	31.40	34.00	30.45	37.40	36.35
2nd	Weight	0.23	0.21	0.29	0.29	0.30	0.29
	Length	39.30	37.70	40.50	41.45	38.90	39.65
3rd	Weight	0.50/0.15†	0.45/0.16	0.55/0.11	0.49/0.14	0.44/0.14	0.49/0.15
	Length	42.95/26.15	43.65/24.10	44.65/29.55	47.45/29.85	44.35/27.80	44.85/30.05
4th	Weight	0.56/0.24	0.54/0.26	0.58/0.25	0.54/0.28	0.49/0.28	0.53/0.26
	Length	43.15/34.40	45.65/34.25	45.20/38.85	49.15/38.55	44.45/37.70	46.45/36.55
5th	Weight	0.71/0.36	0.72/0.39	0.70/0.33	0.62/0.36	0.69/0.35	0.61/0.32
	Length	42.85/41.9	47.75/40.4	46.10/45.70	50.85/44.65	47.01/43.45	47.90/42.80
6th	Weight	0.95/0.44	1.04/0.44	0.95/0.38	0.74/0.40	0.74/0.30	0.77/0.32
	Length	45.30/47.00	49.55/46.00	44.50/50.60	51.60/50.65	46.40/45.75	49.20/45.60
7th	Weight	0.80/0.38	0.94/0.40	0.49/0.13	0.50/0.13	0.51/0.13	0.40/0.14
	Length	46.05/52.1	43.85/49.65	45.85/40.80	55.30/37.40	53.95/44.35	52.00/44.85

Birds		L		P		Z	
Rib No.		Right	Left	Right	Left	Right	Left
1st	Weight	0.15	0.15	0.11	0.14	0.16	0.18
	Length	33.15	33.60	31.40	32.20	30.85	33.80
2nd	Weight	0.34	0.30	0.26	0.33	0.32	0.37
	Length	39.50	37.70	40.75	40.40	38.40	39.35
3rd	Weight	0.42/-	0.48/-	0.58/0.13	0.47/0.14	0.50/0.13	0.54/0.15
	Length	41.45/24.11	44.35/25.05	43.80/28.80	47.05/28.70	43.85/30.00	44.70/27.50
4th	Weight	0.57/0.21	0.56/0.21	0.69/0.31	0.60/0.30	0.65/0.29	0.62/0.34
	Length	44.75/34.30	49.00/35.25	45.35/39.05	47.81/37.35	41.65/38.70	45.50/37.55
5th	Weight	0.70/0.38	0.71/0.40	0.66/0.40	0.69/0.43	0.74/0.45	0.68/0.42
	Length	45.90/42.35	53.20/42.50	46.46/45.25	53.70/44.35	39.75/45.30	45.95/43.60
6th	Weight	0.95/0.47	0.86/0.46	0.72/0.34	0.74/0.37	0.78/0.34	0.66/0.37
	Length	54.00/47.25	44.10/47.30	43.85/47.85	55.90/44.90	40.35/46.90	46.25/46.25
7th	Weight	0.76/0.39	0.84/0.49	0.52/0.16	0.59/0.20	0.47/0.11	0.49/0.11
	Length	55.50/48.15	49.40/48.10	56.80/44.90	49.15/47.00	41.15/32.70	42.00/31.00

†The first number indicates the weight or length of vertebral rib where the second number for the sternal rib.

Rib's weight in gram and the length in millimeter.

Table D.16 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird D)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	27.0	33.0	292	42.0	47.0
	L	26.0	34.0	308	44.0	49.0
	R/L %	103.8	97.1	94.8	95.5	95.9
2nd Rib	R	37.0	36.0	527	33	48.0
	L	34.0	39.0	614	46.0	51.0
	R/L %	108.8	92.3	85.8	71.6	94.1
3rd Rib	R	60.5	36.0	853	29.5	52.0
	L	56.5	40.0	990	34.5	59.0
	R/L %	107.1	90.0	86.2	85.5	88.1
4th Rib	R	63.5	34.0	983	29.0	55.0
	L	62.0	41.0	1181	33.5	61.0
	R/L %	102.4	82.9	83.2	86.6	90.2
5th Rib	R	68.0	35.0	914	27.0	54.0
	L	60.0	44.0	1115	30.0	60.0
	R/L %	113.3	79.5	82.0	90.9	90.0
6th Rib	R	73.0	40.0	1141	24.0	54.0
	L	68.5	44.0	1286	32.5	58.0
	R/L %	106.6	90.9	88.7	73.8	93.1
7th Rib	R	75.0	36.0	1173	31.0	61.0
	L	72.0	45.0	1330	38.0	68.0
	R/L %	104.2	80.0	88.2	81.6	989.7

Table D.17 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird J)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	33.0	30.0	422	46.5	42.0
	L	29.0	31.0	433	51.5	44.0
	R/L %	113.8	96.8	97.5	90.3	95.5
2nd Rib	R	53.0	34.0	690	40.5	49.0
	L	50.0	40.0	738	43.5	53.0
	R/L %	106.0	85.0	93.5	93.1	92.5
3rd Rib	R	65.0	36.0	1158	32.0	55.0
	L	61.0	39.0	1338	35.0	62.0
	R/L %	106.6	92.3	83.4	91.4	88.7
4th Rib	R	65.0	30.0	1025	29.5	55.0
	L	61.0	40.0	1298	34.0	61.0
	R/L %	106.6	75.0	79.0	86.8	90.2
5th Rib	R	68.0	35.0	1090	25.0	53.0
	L	66.0	40.0	1257	33.0	60.0
	R/L %	103.0	87.5	86.7	75.8	88.3
6th Rib	R	70.0	30.0	1039	30.5	55.0
	L	68.0	45.0	1231	32.5	59.0
	R/L %	102.9	66.7	84.4	92.3	93.2
7th Rib	R	69.0	40.0	1096	19.0	51.0
	L	67.0	54.0	1242	24.0	58.0
	R/L %	103.0	74.1	88.2	79.2	87.9

Table D.18 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird L)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	29.0	35.0	324	39.5	34.0
	L	27.5	36.0	397	41.0	35.0
	R/L %	105.5	97.2	81.6	96.3	97.1
2nd Rib	R	36.0	30.0	524	36.0	43.0
	L	32.0	41.0	630	42.0	50.0
	R/L %	112.5	73.2	83.2	85.7	86.0
3rd Rib	R	58.0	37.0	768	38.0	44.0
	L	55.0	43.0	994	41.0	50.0
	R/L %	105.5	86.0	77.3	92.7	88.0
4th Rib	R	66.0	38.0	1008	27.0	48.0
	L	63.0	45.0	1273	35.0	65.0
	R/L %	104.8	84.4	79.2	77.1	73.8
5th Rib	R	68.5	34.0	990	27.5	45.0
	L	64.6	52.0	1205	36.5	60.0
	R/L %	106.0	65.4	82.2	75.3	75.0
6th Rib	R	78.0	32.0	812	28.5	42.0
	L	72.0	39.0	1069	32.0	64.0
	R/L %	108.3	82.1	76.0	89.1	65.6
7th Rib	R	73.0	40.0	1213	21.5	52.0
	L	72.0	50.0	1489	34.5	59.0
	R/L %	101.4	80.0	81.5	62.3	88.1

Table D.19 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird P)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	29.0	29.0	366	35.0	32.0
	L	30.0	36.0	483	66.0	33.0
	R/L %	96.7	80.6	75.8	53.0	97.0
2nd Rib	R	39.0	33.0	757	34.5	40.0
	L	40.0	46.0	811	50.0	49.0
	R/L %	97.5	71.7	93.3	69.0	81.6
3rd Rib	R	64.0	40.0	1166	35.5	51.0
	L	63.0	45.0	1463	43.0	57.0
	R/L %	101.6	88.9	79.7	81.3	89.5
4th Rib	R	65.0	40.0	1152	31.0	54.0
	L	69.0	45.0	1305	36.0	59.0
	R/L %	98.6	88.9	88.3	86.1	91.5
5th Rib	R	68.0	40.0	1101	24.5	50.0
	L	68.0	44.0	1281	33.0	55.0
	R/L %	100.0	90.9	85.9	74.2	90.9
6th Rib	R	75.0	35.0	1124	24.0	52.0
	L	71.0	55.0	1303	30.0	56.0
	R/L %	105.6	63.6	86.3	80.0	92.9
7th Rib	R	75.0	45.0	1256	25	52.0
	L	73.0	52.0	1452	39	58.0
	R/L %	102.7	86.5	86.5	64.1	89.7

Table D.20 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird K)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	44.0	35.0	306	44.0	40.0
	L	40.0	37.0	432	56.0	43.0
	R/L %	110.0	94.6	70.8	78.6	93.0
2nd Rib	R	55.0	35.0	628	41.5	48.0
	L	52.0	41.0	694	54.5	58.0
	R/L %	105.8	97.2	90.5	76.1	82.8
3rd Rib	R	66.0	36.0	952	32.0	47.0
	L	62.0	43.0	1192	35.0	52.0
	R/L %	106.5	83.7	79.8	91.4	90.4
4th Rib	R	68.0	40.0	1045	25.0	52.0
	L	65.0	45.0	1215	31.5	56.0
	R/L %	104.6	88.9	86.0	79.4	92.9
5th Rib	R	70.0	45.0	1060	21.0	48.0
	L	67.0	50.0	1247	27.5	53.0
	R/L %	104.5	90.0	85.0	76.4	90.6
6th Rib	R	71.0	44.0	1123	36.0	49.0
	L	66.0	50.0	1262	39.0	54.0
	R/L %	107.6	88.0	89.0	92.30	90.7
7th Rib	R	68.0	46.0	1207	37.0	47.0
	L	65.0	52.0	1344	47.5	53.0
	R/L %	104.6	88.5	89.8	78.7	88.7

Table D.21 - Some Measurements on the Chickens Ribs at Age 100 Days (Bird Z)

Rib No.		Arc Length(mm)	Chord Length(mm)	Enclosed Area(mm^2)	Angle (^{o})	Height (mm)
1st Rib	R	27.0	27.0	375	45.5	43.0
	L	29.0	32.0	394	58.0	47.0
	R/L %	93.1	84.4	95.2	78.4	91.5
2nd Rib	R	55.0	30.0	714	40.0	48.0
	L	54.0	34.0	760	50.0	54.0
	R/L %	101.9	88.2	93.9	80.0	88.9
3rd Rib	R	65.0	30.0	932	31.5	50.0
	L	62.0	35.0	1187	40.0	58.0
	R/L %	104.8	85.7	78.5	78.8	86.2
4th Rib	R	67.0	30.0	975	28.5	50.0
	L	65.0	35.0	1190	35.0	58.0
	R/L %	103.1	85.7	81.9	81.4	86.2
5th Rib	R	67.0	31.0	904	26.0	52.0
	L	65.0	37.0	1065	33.5	59.0
	R/L %	103.1	83.8	84.9	78.8	88.1
6th Rib	R	71.0	32.0	975	24.5	53.0
	L	68.0	36.0	1073	35.0	61.0
	R/L %	104.4	88.9	90.0	70.0	86.9
7th Rib	R	52.5	33.0	994	29.5	54.0
	L	44.0	39.0	1095	39.0	60.0
	R/L %	119.3	84.6	90.8	75.6	90.0